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Sai et al.

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(45) **Date of Patent: Aug. 10, 2010**

(54) **OPTICAL UNIT AND EXPOSURE APPARATUS HAVING THE SAME**

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(51) **Int. Cl.**
G02B 5/08 (2006.01)
G02B 7/188 (2006.01)
G02B 26/08 (2006.01)

(52) **U.S. Cl.** **359/847**; 359/224.1; 359/849

(58) **Field of Classification Search** 359/489, 359/849, 848, 882, 224.1
See application file for complete search history.

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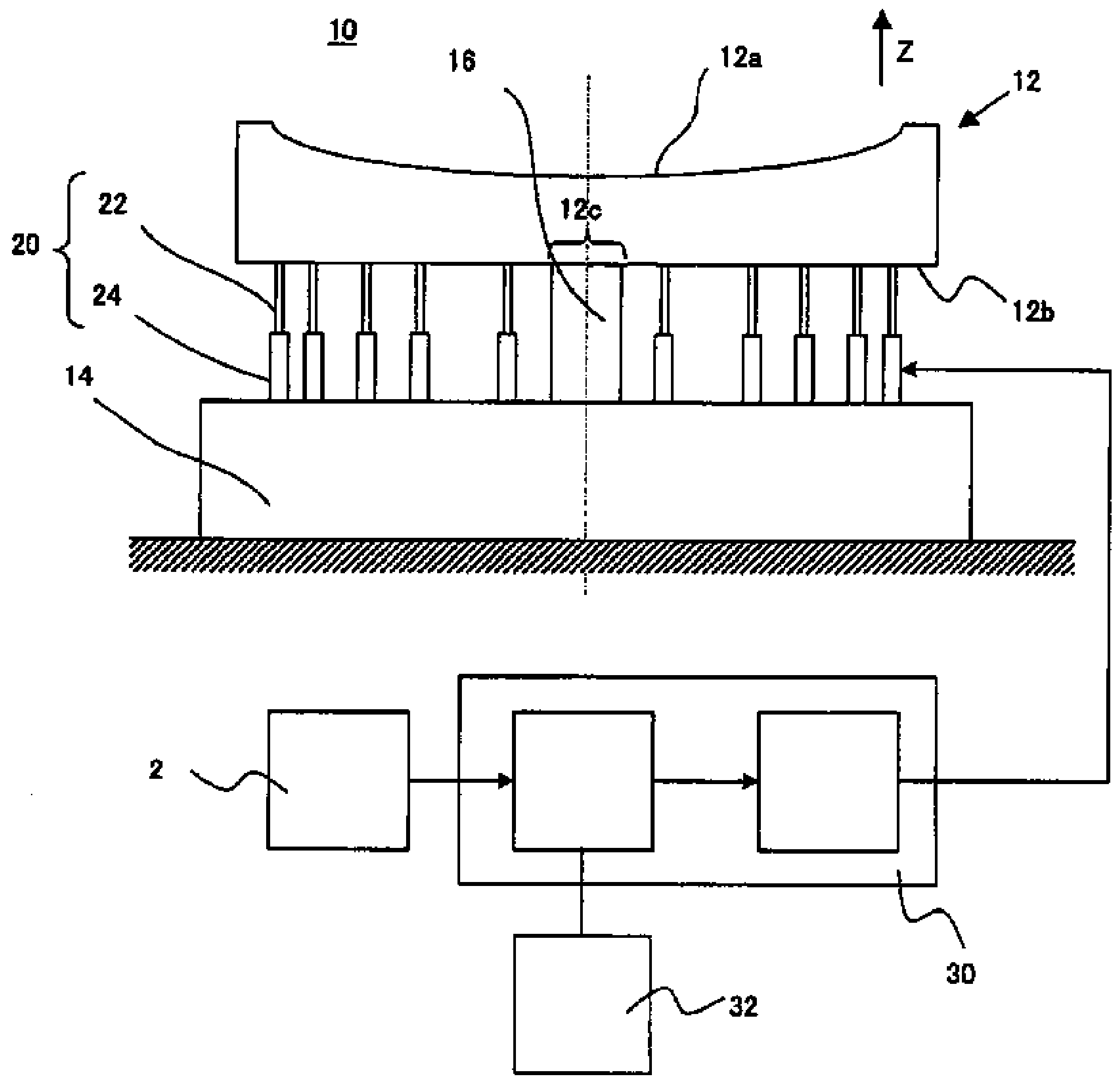
(74) *Attorney, Agent, or Firm*—Fitzpatrick, Cella, Harper & Scinto

(57) **ABSTRACT**

An optical unit including a plate, an optical element, a fixing device for partially fixing the optical element against the plate, and a deforming device, located between the plate and the optical element, for applying a deforming force to the optical element to change a surface shape of the optical element. The deforming device includes poles for contacting a back face of the optical element, and actuators for driving the poles against the plate.

11 Claims, 14 Drawing Sheets



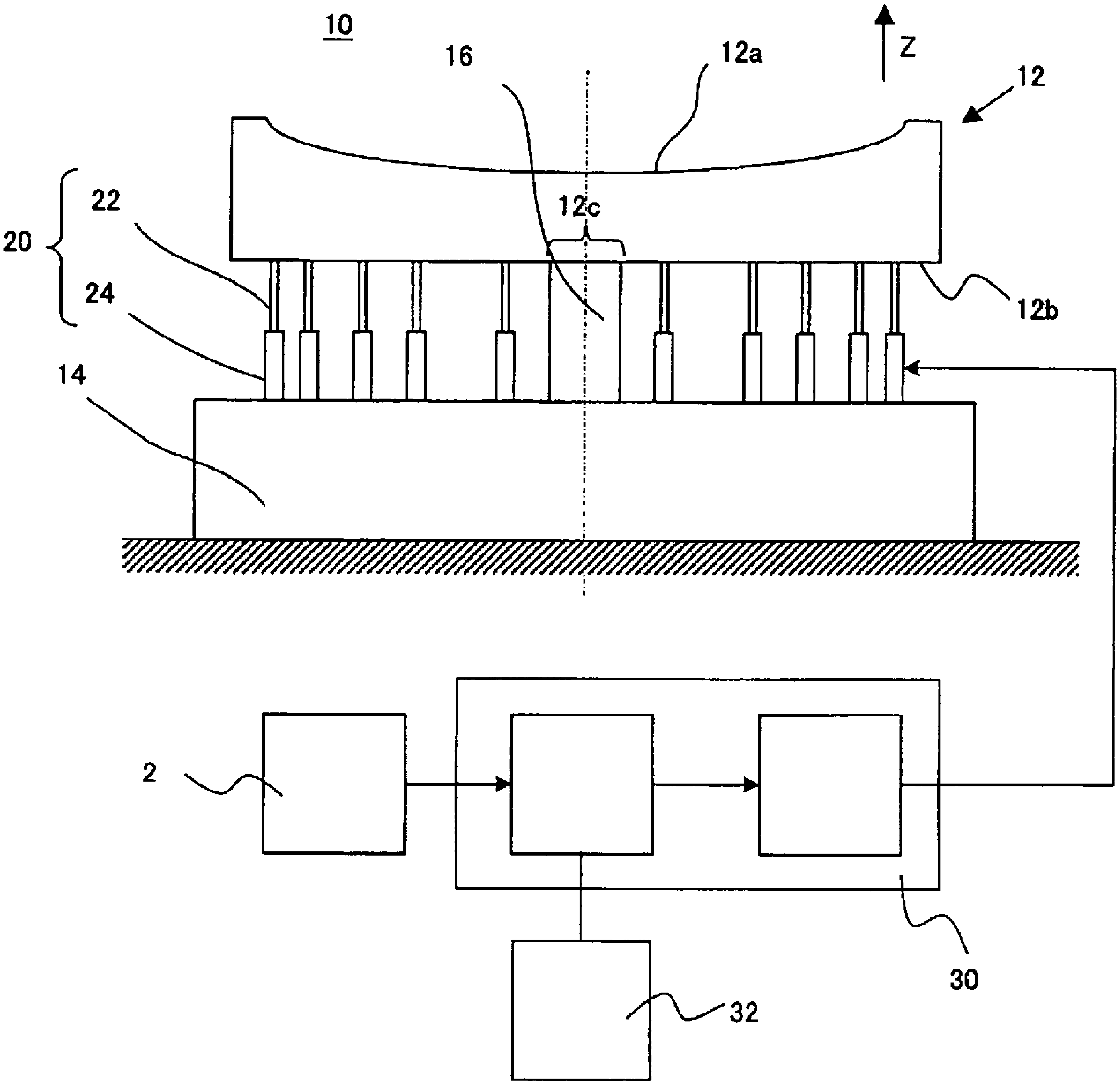


FIG. 1

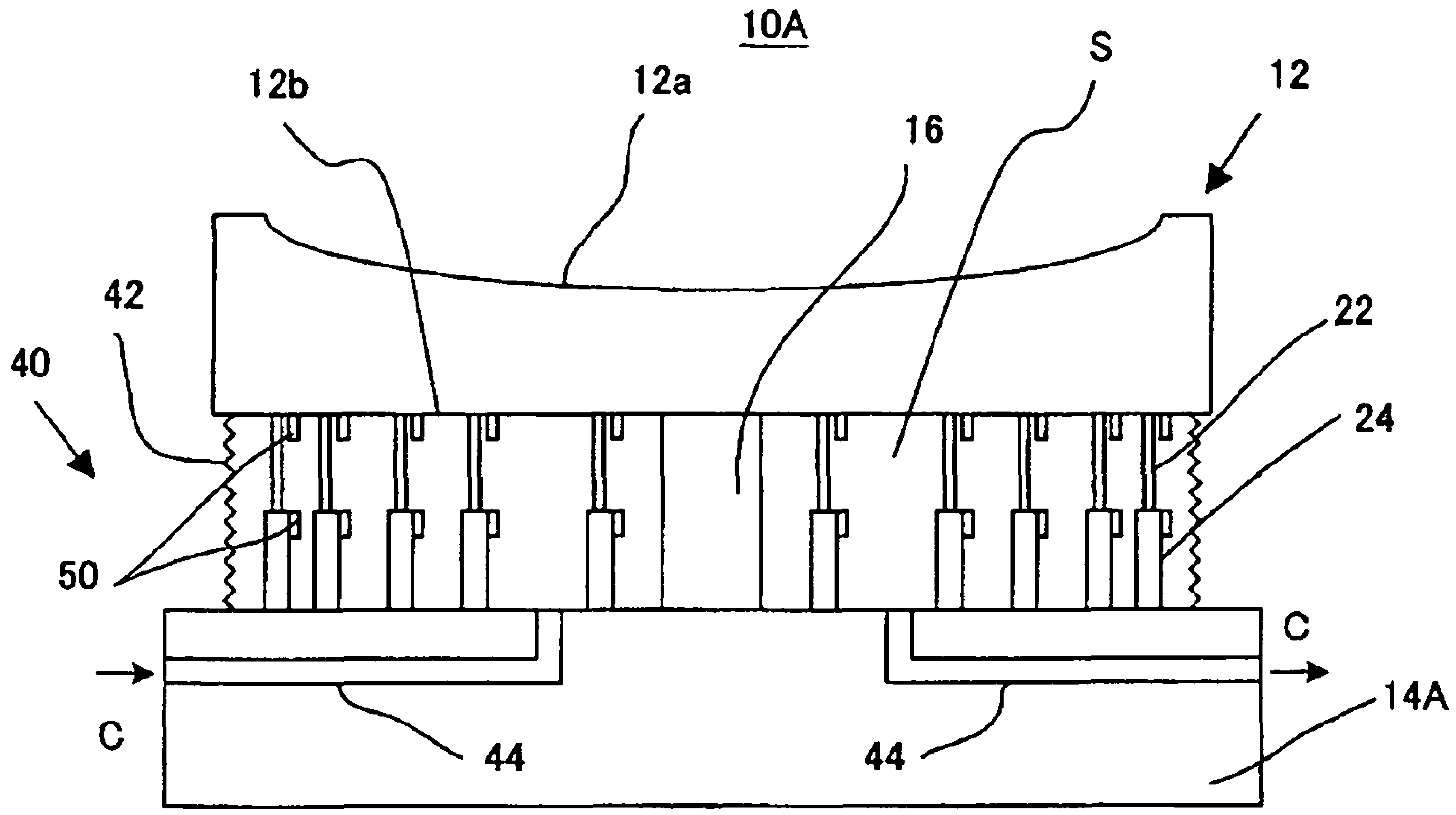


FIG. 2

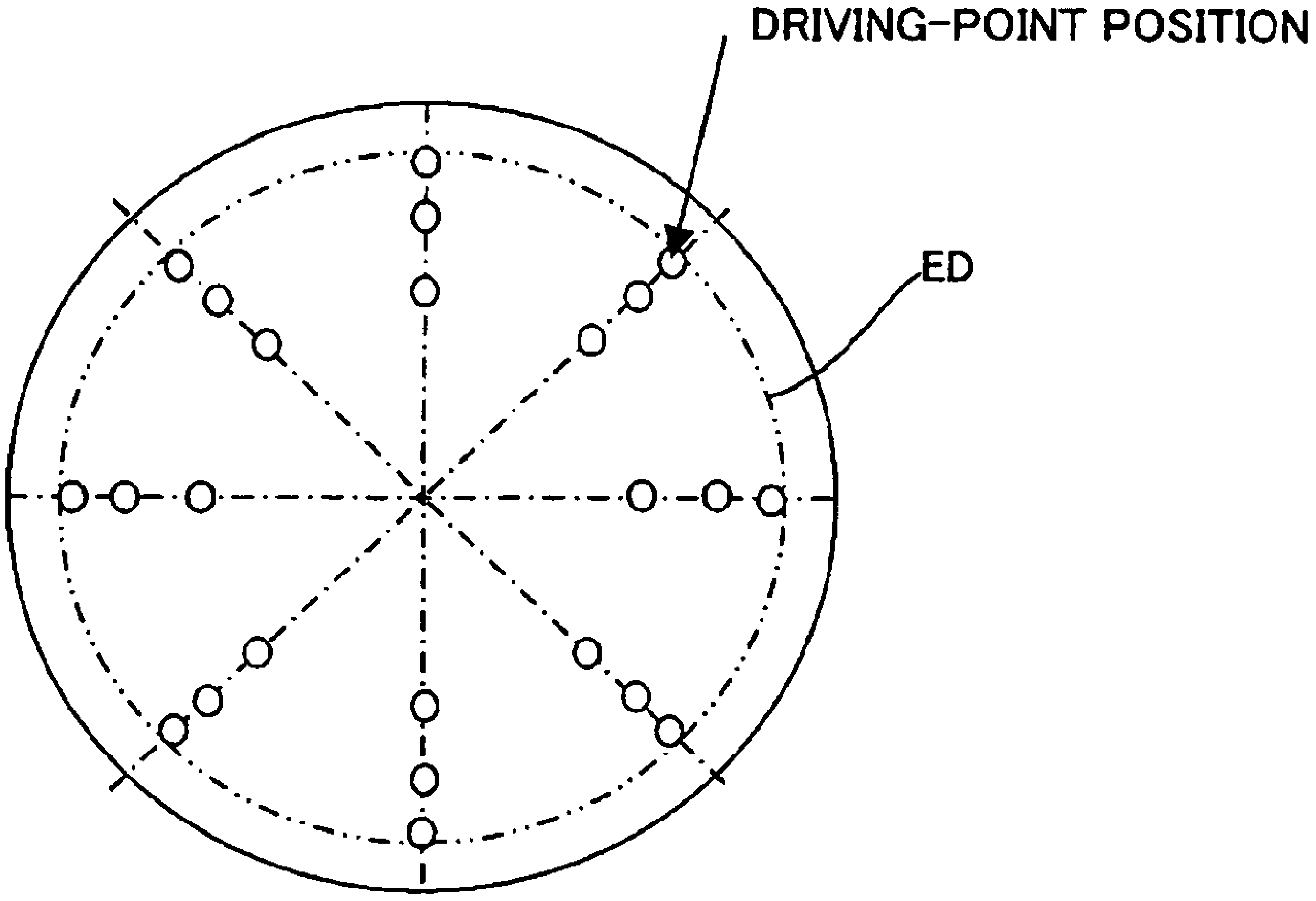


FIG. 3A

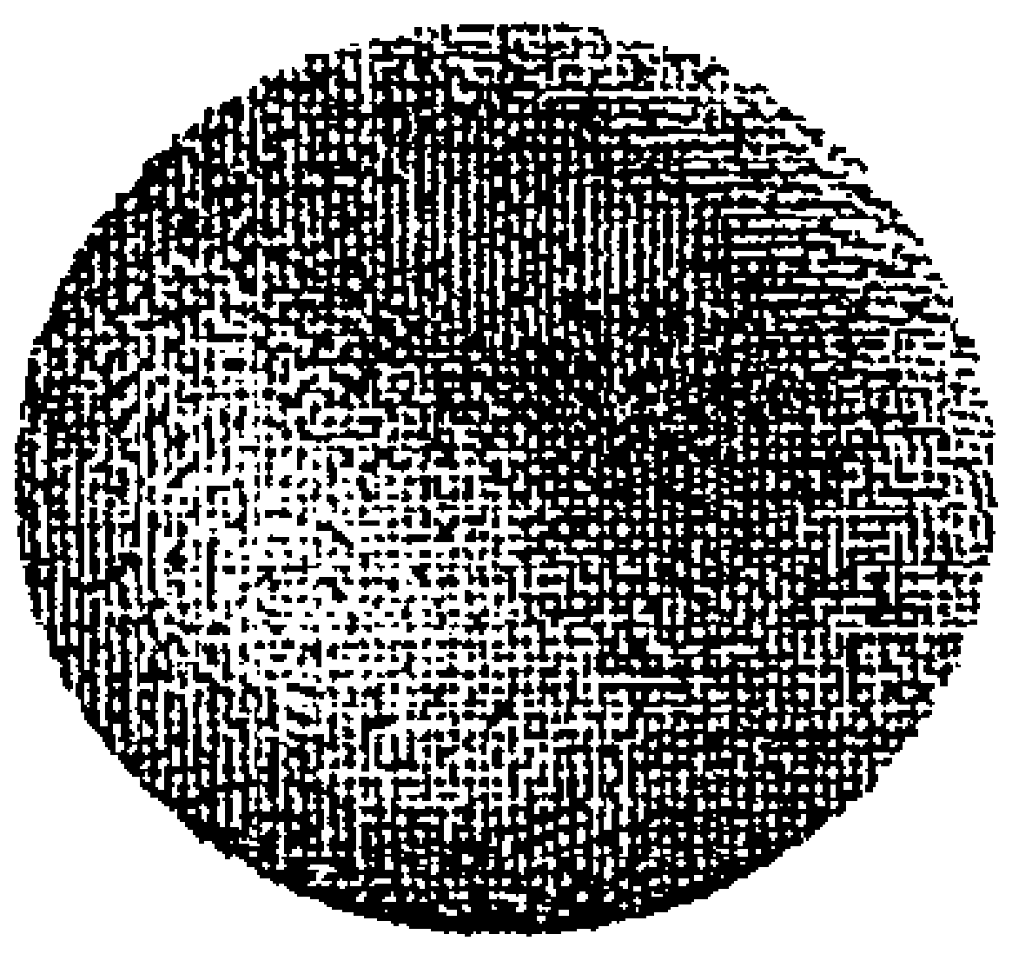


FIG. 3B

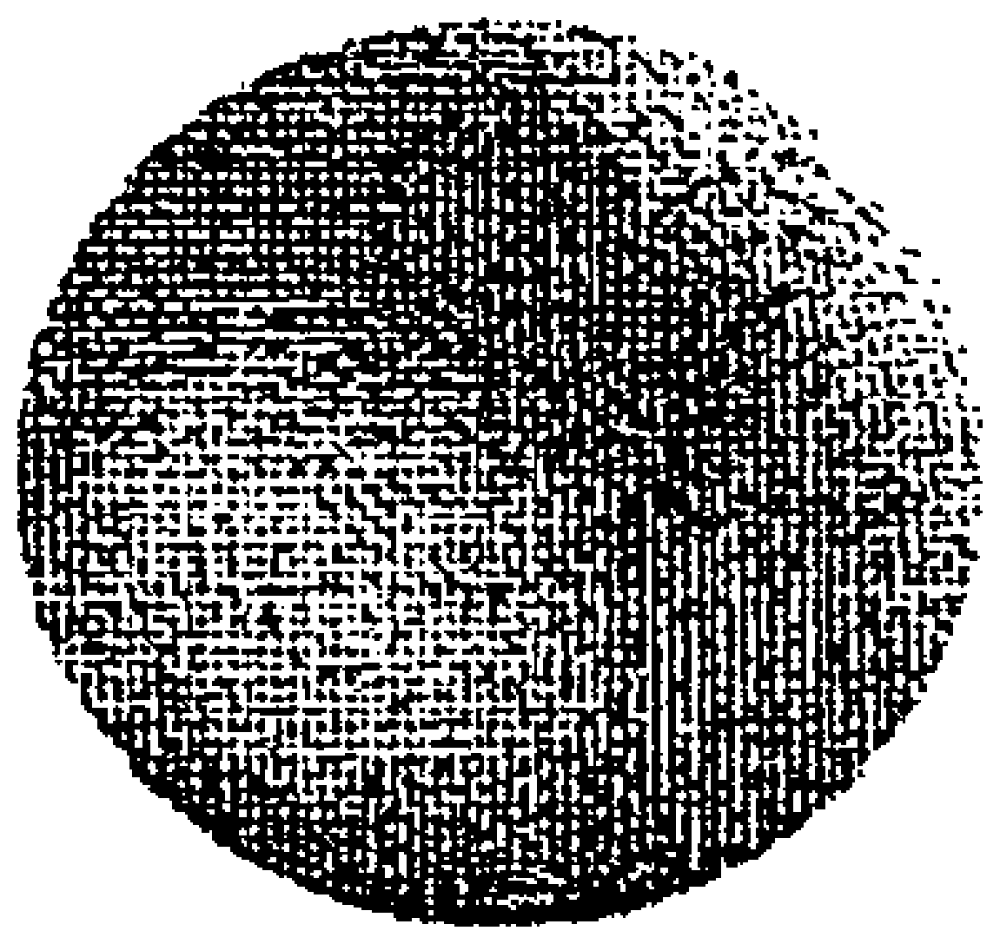


FIG. 3C

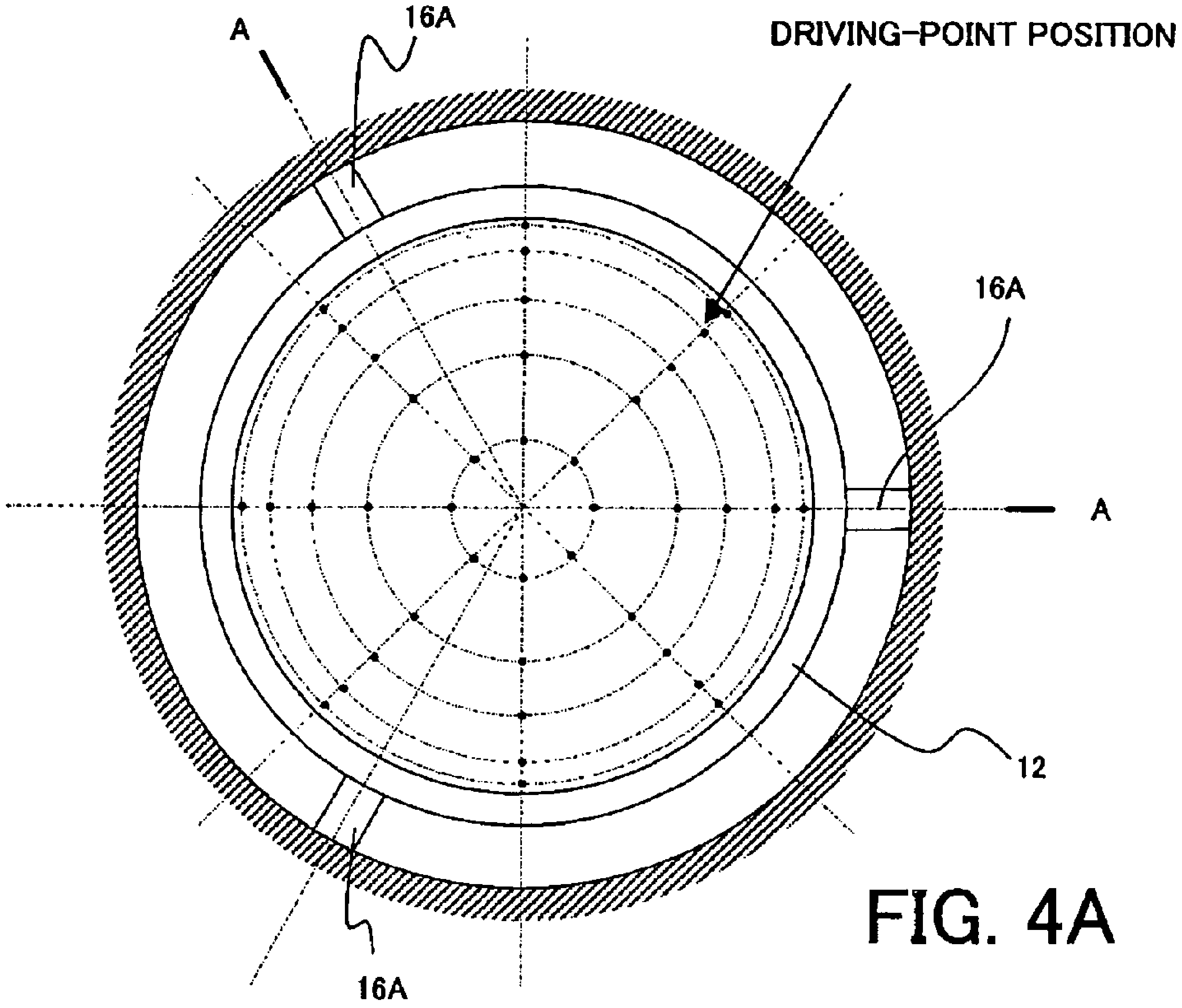

A
16A
DRIVING-POINT POSITION
16A
A
12
16A

FIG. 4A

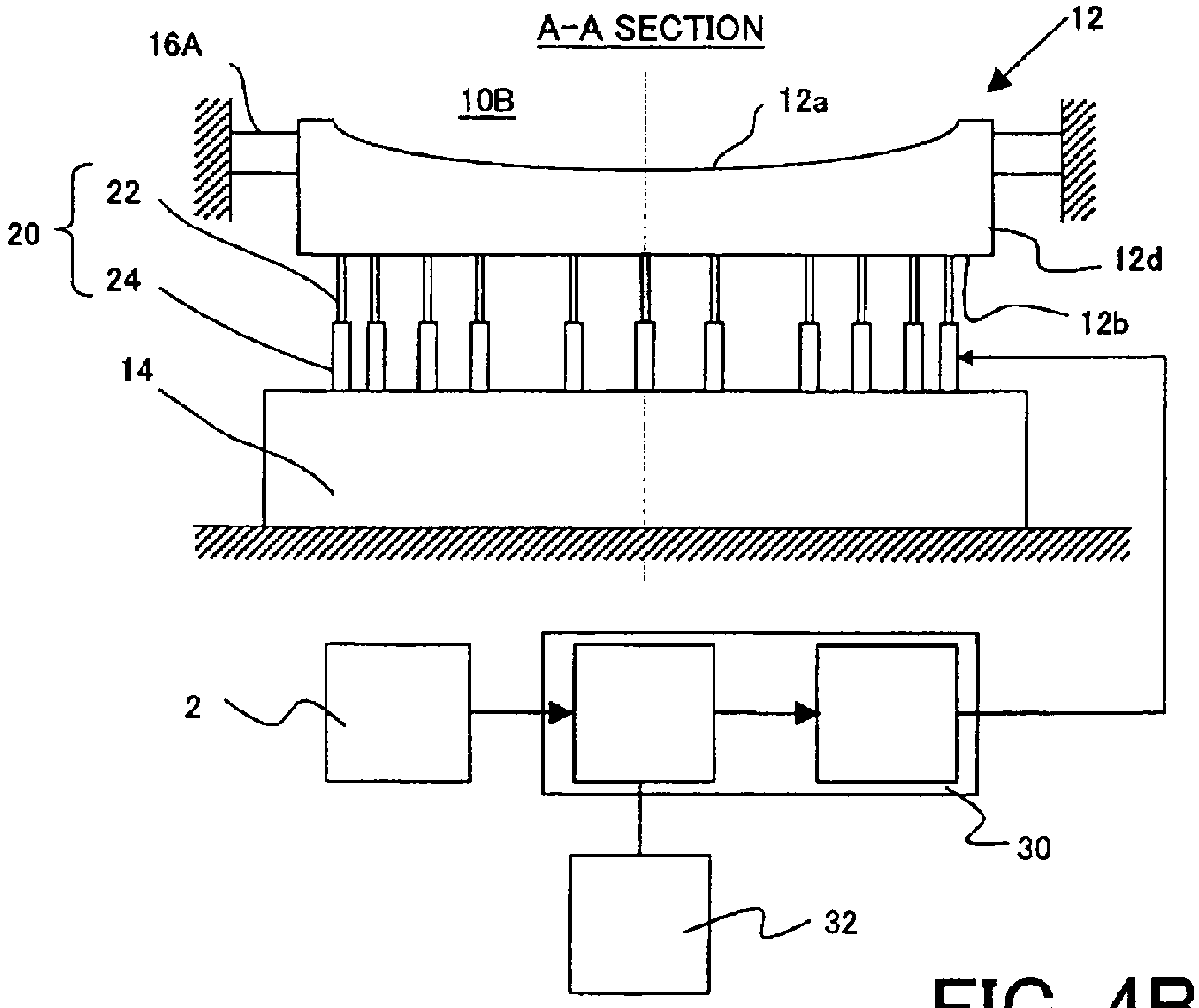

A-A SECTION
16A
12
10B
12a
20
22
24
12d
12b
14
2
30
32

FIG. 4B

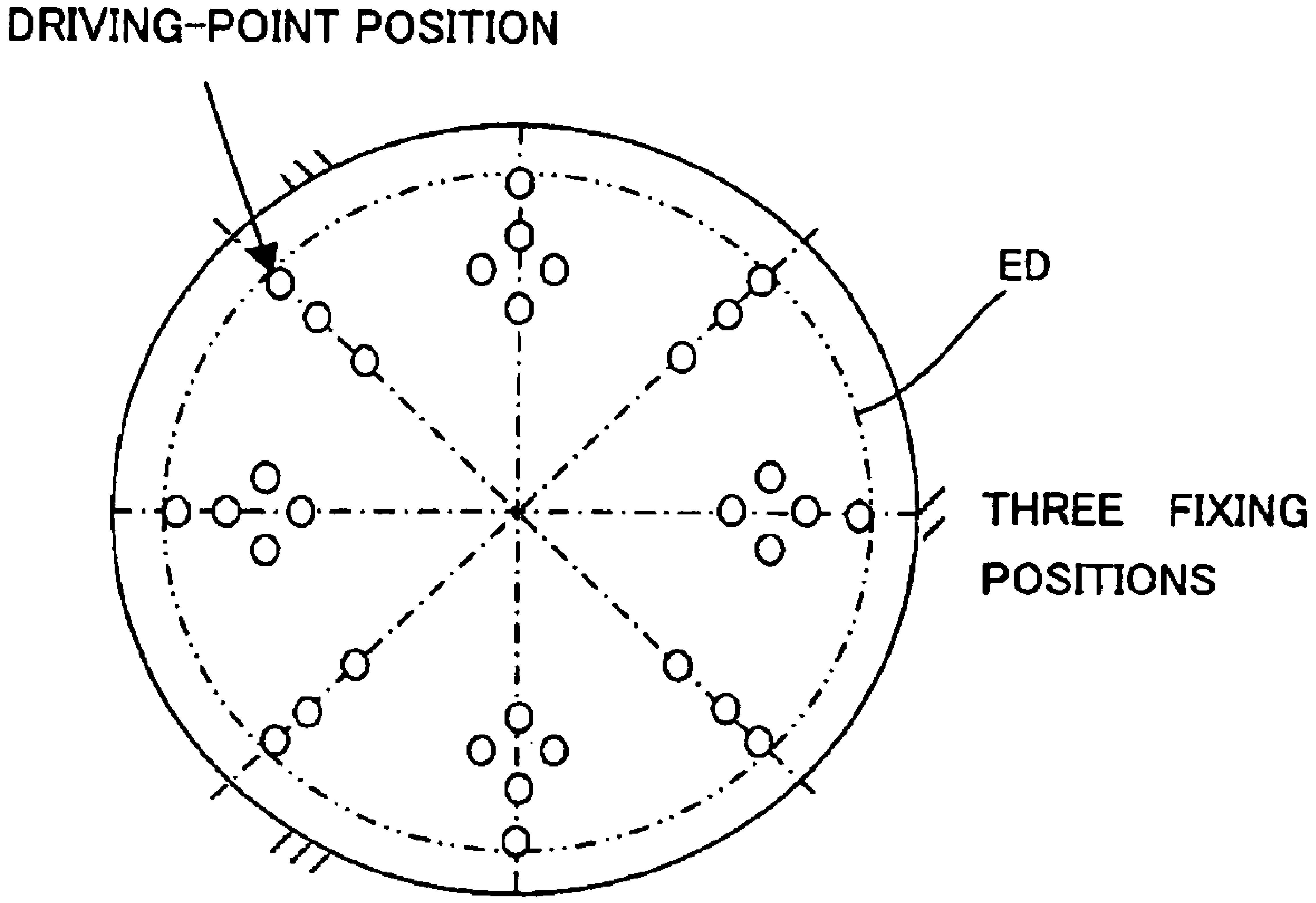


FIG. 5A

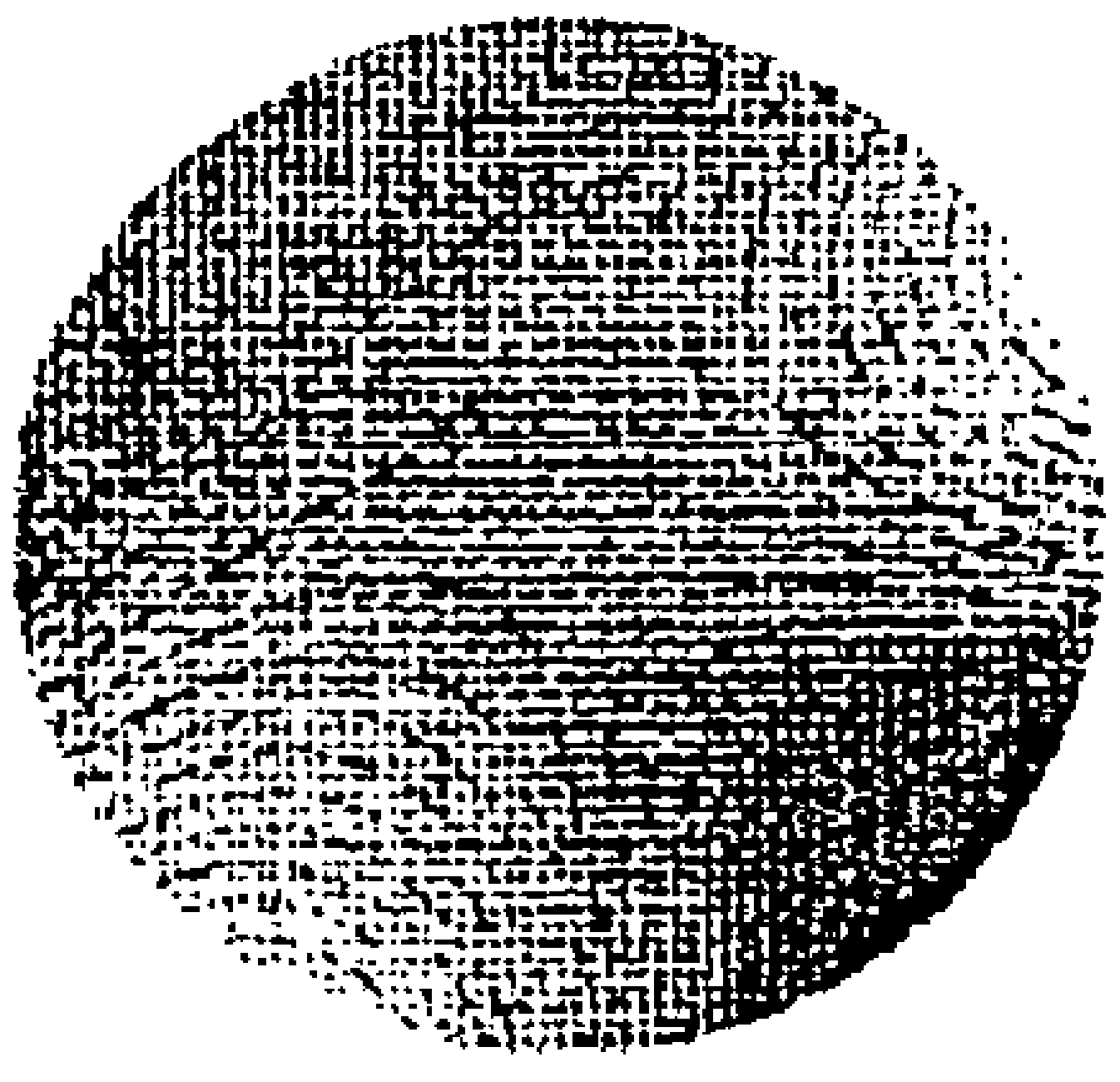


FIG. 5B

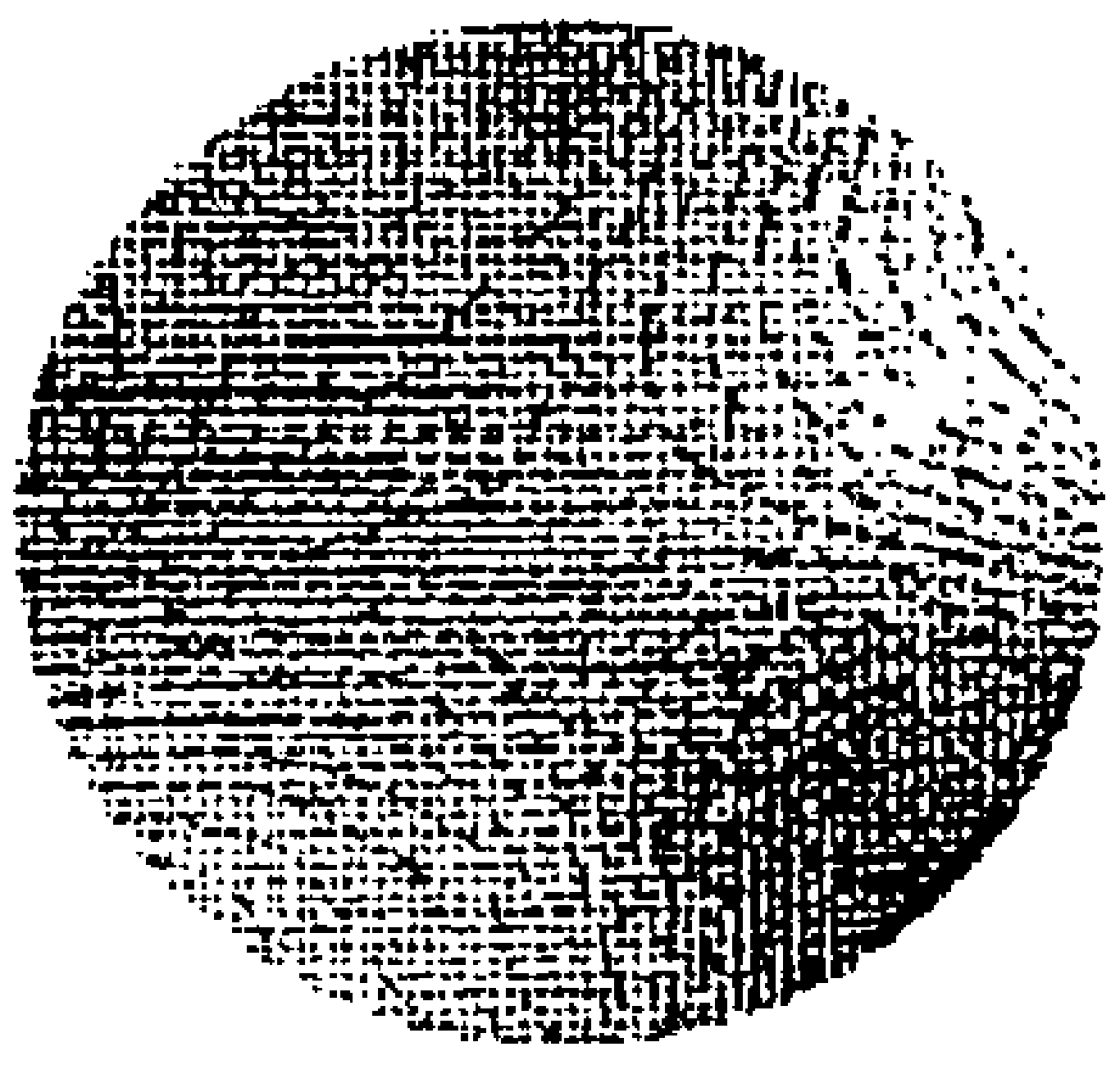


FIG. 5C

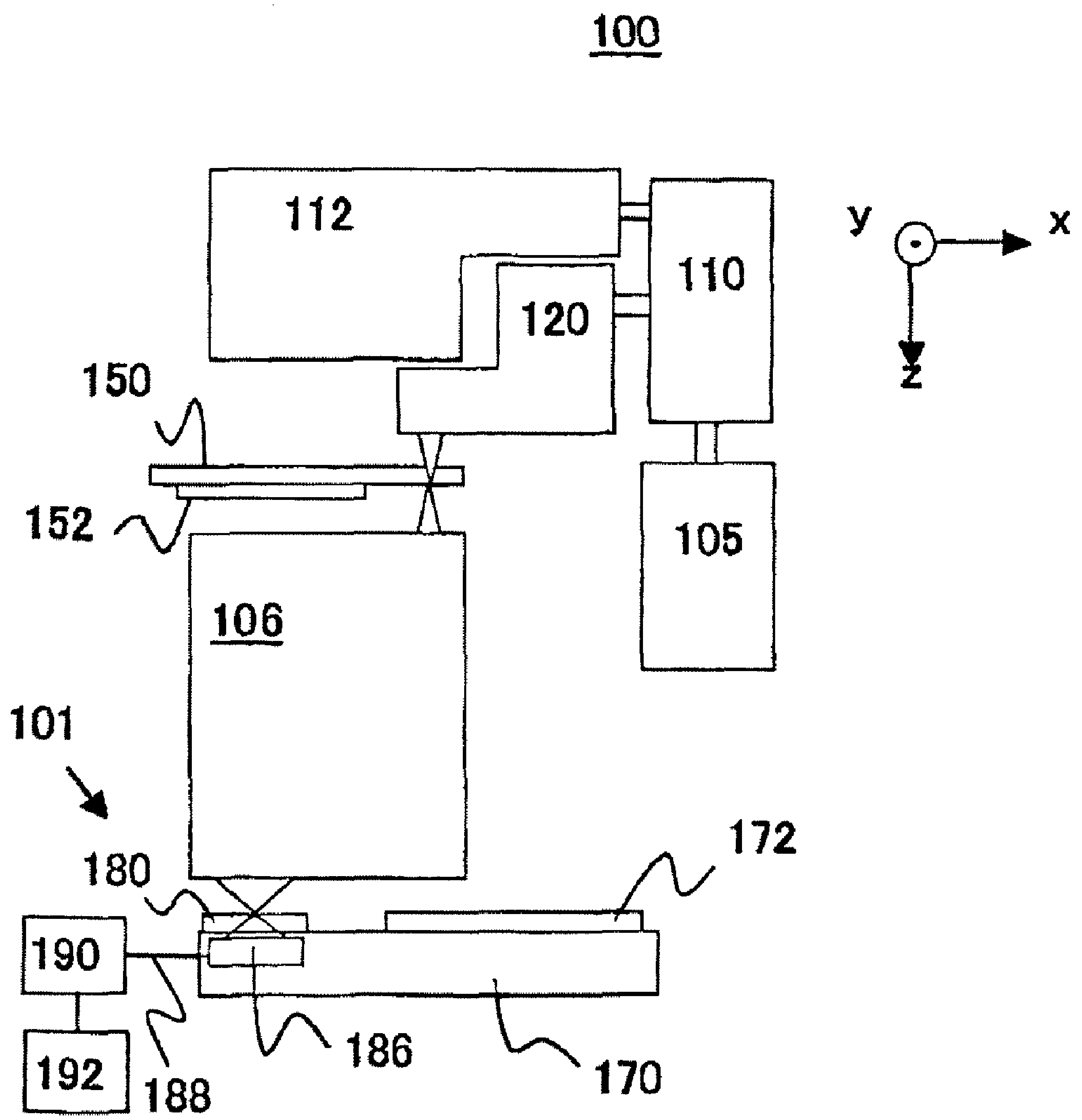

100
112
110
120
y
x
z
150
152
105
106
101
180
172
190
192
188
186
170

FIG. 6

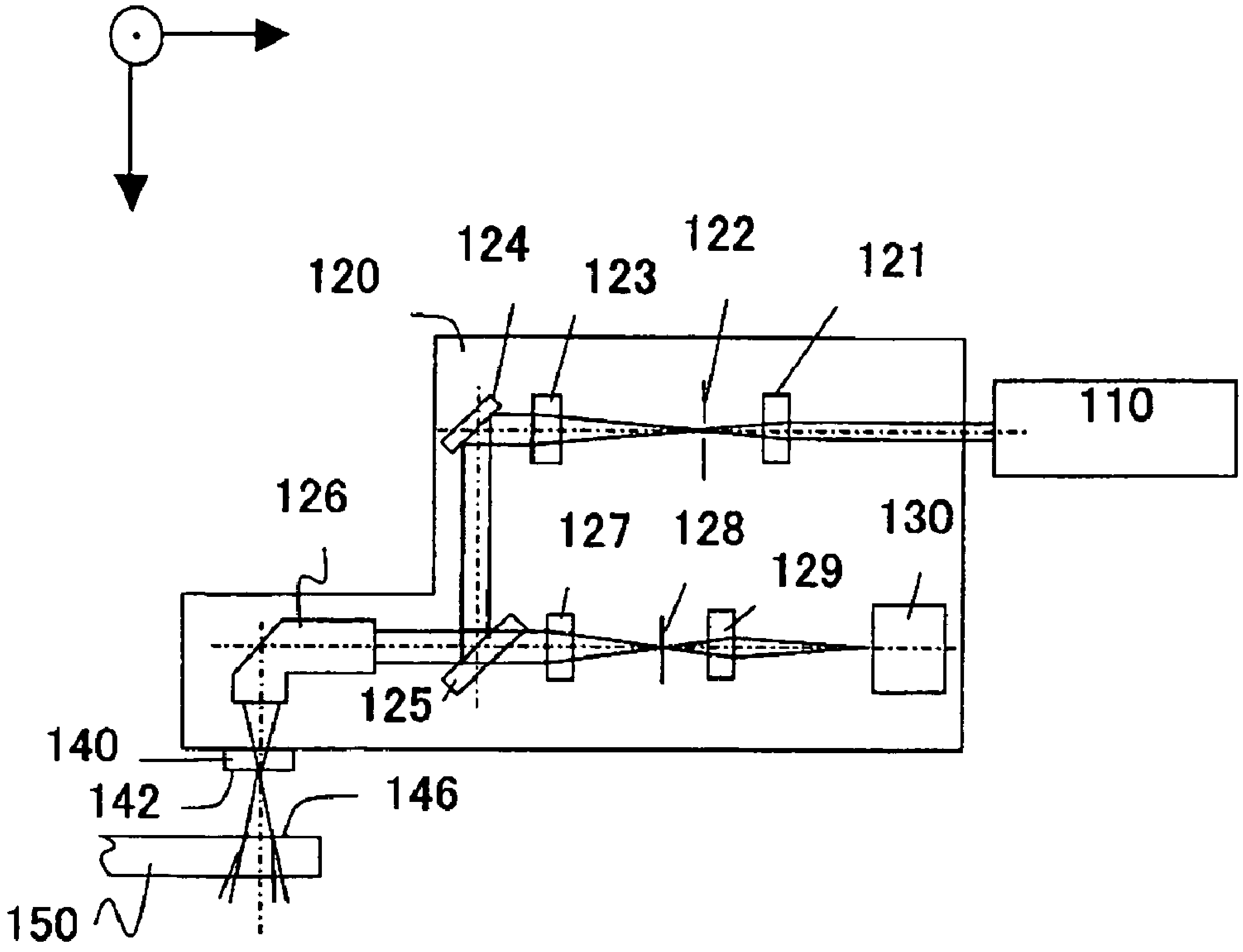


FIG. 7

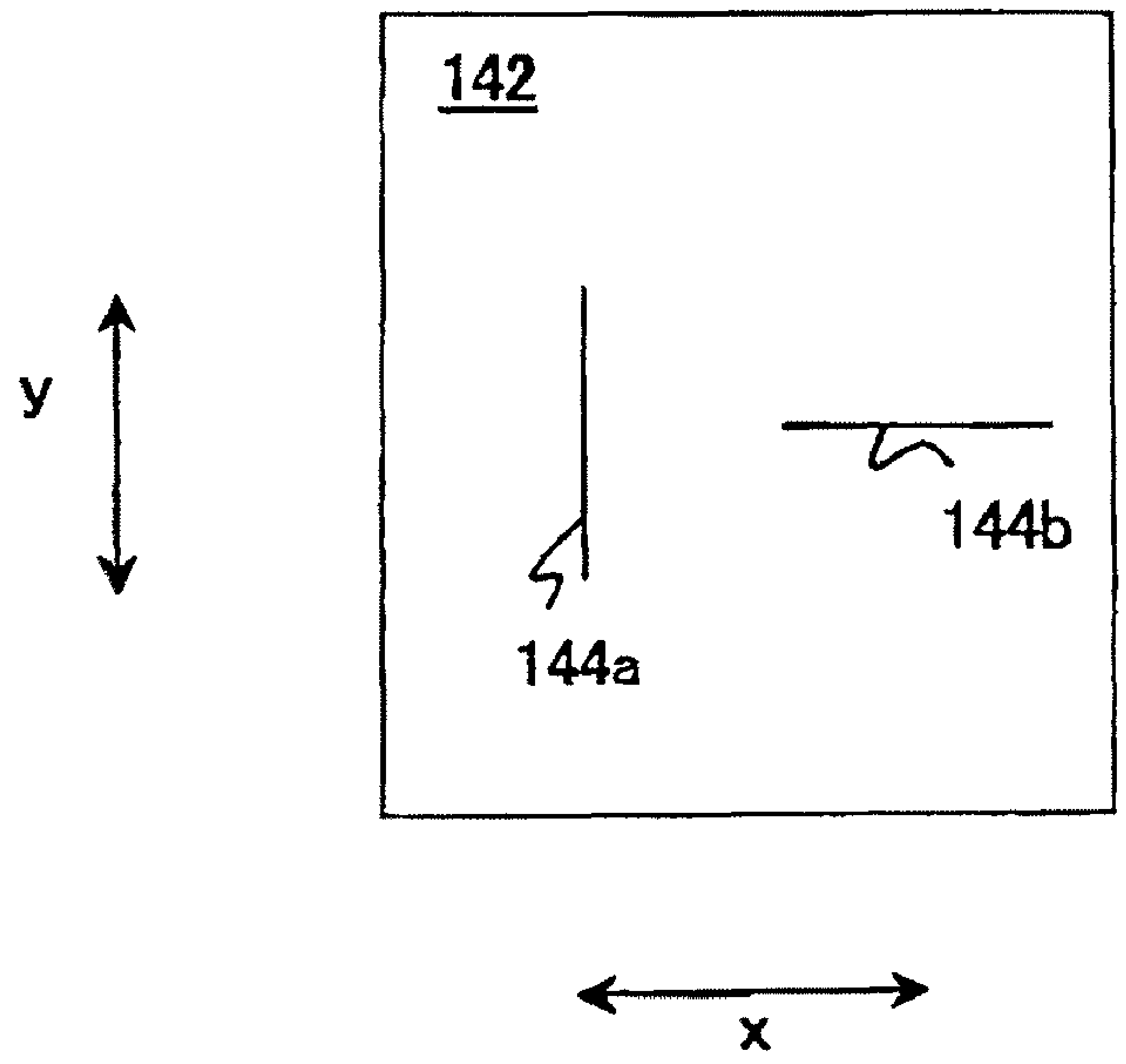


FIG. 8

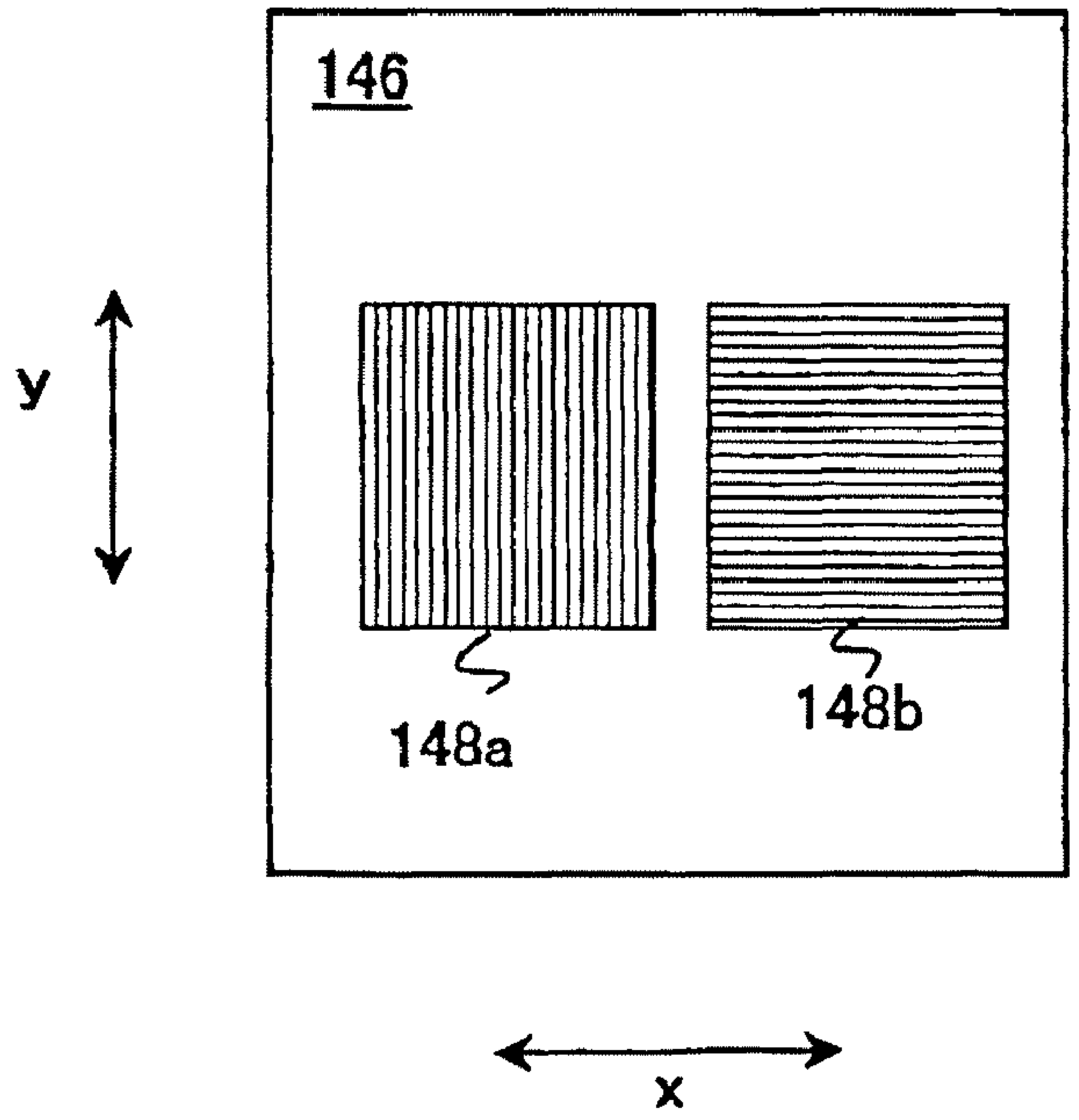


FIG. 9

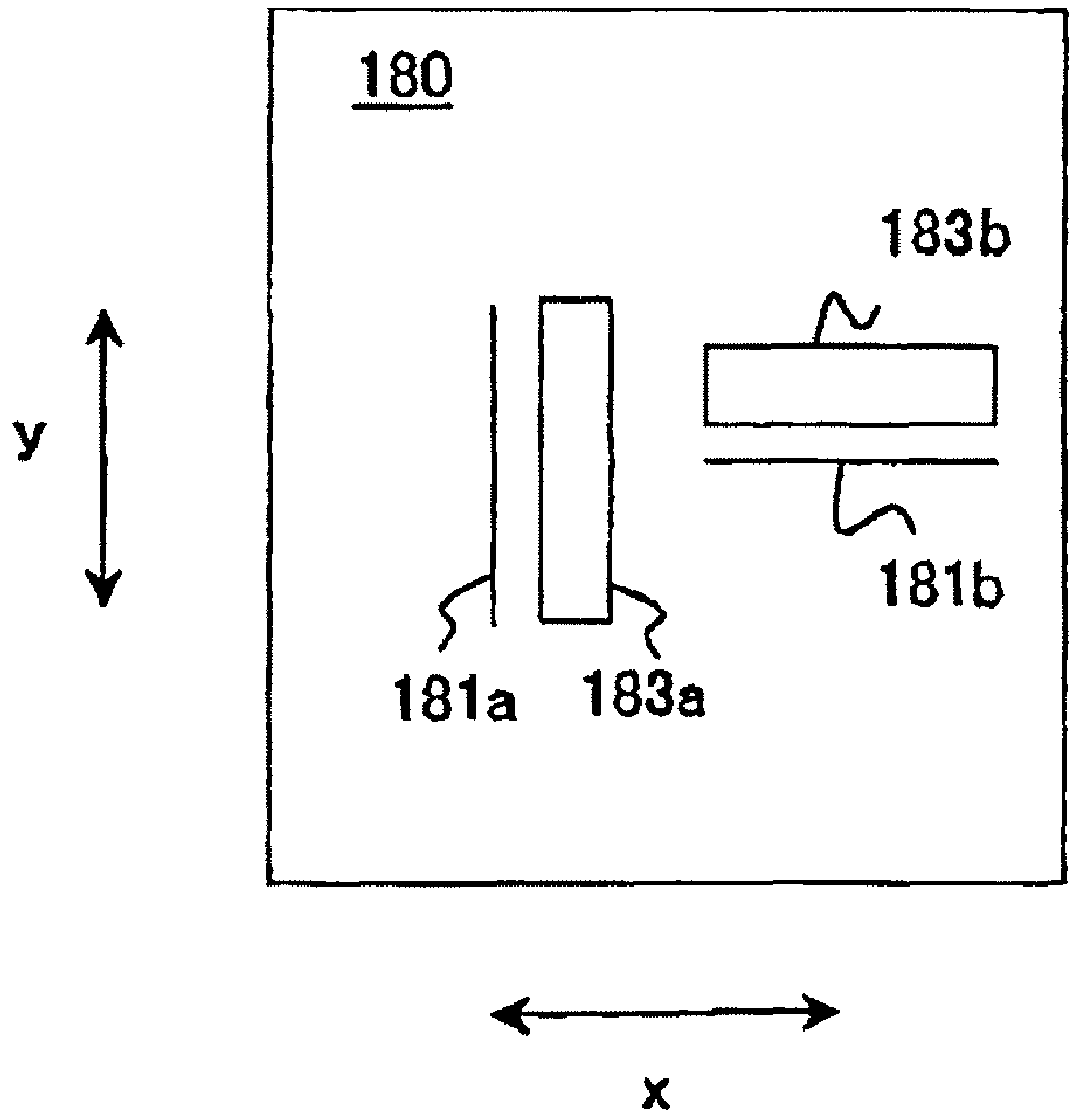


FIG. 10

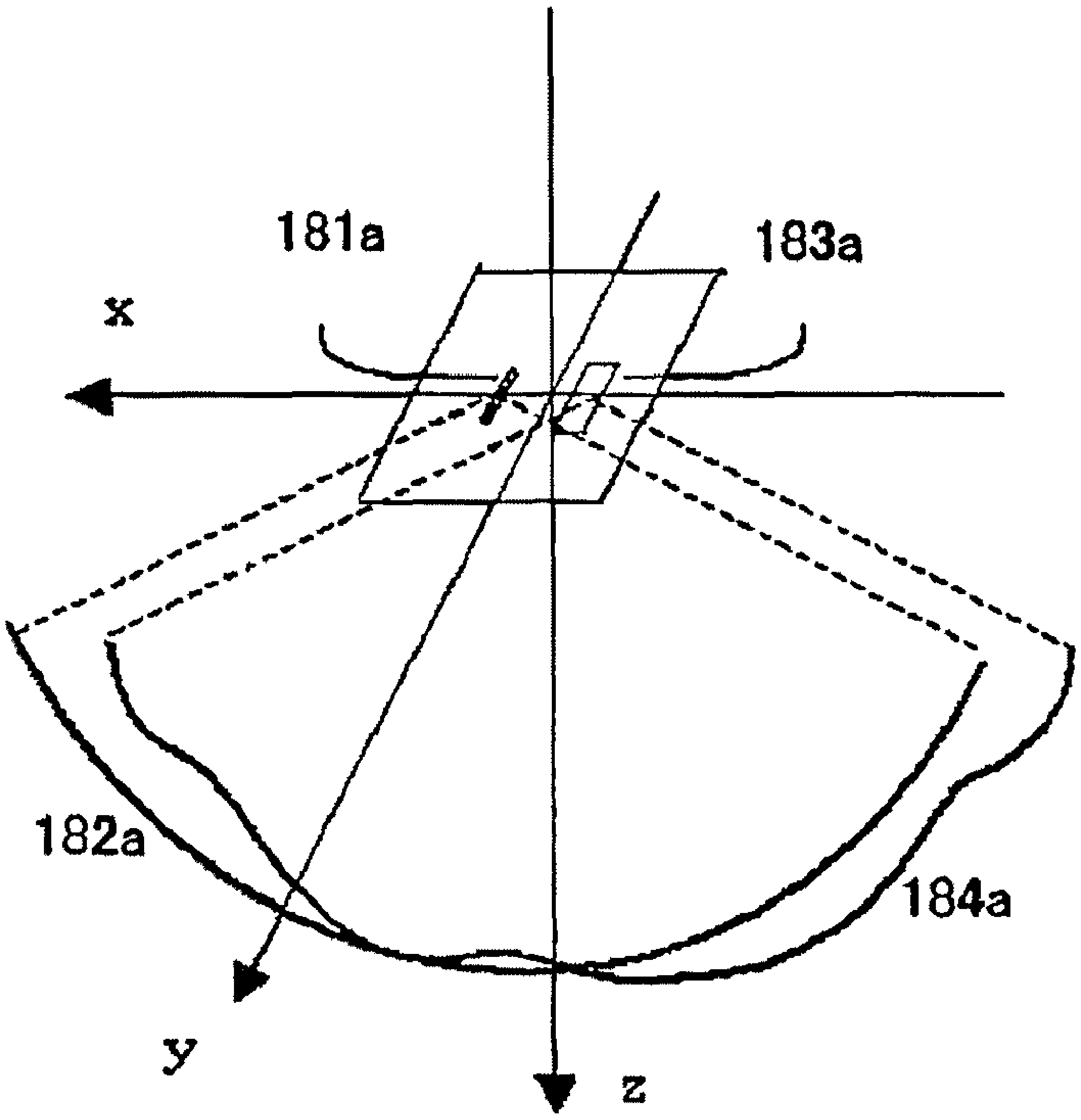


FIG. 11

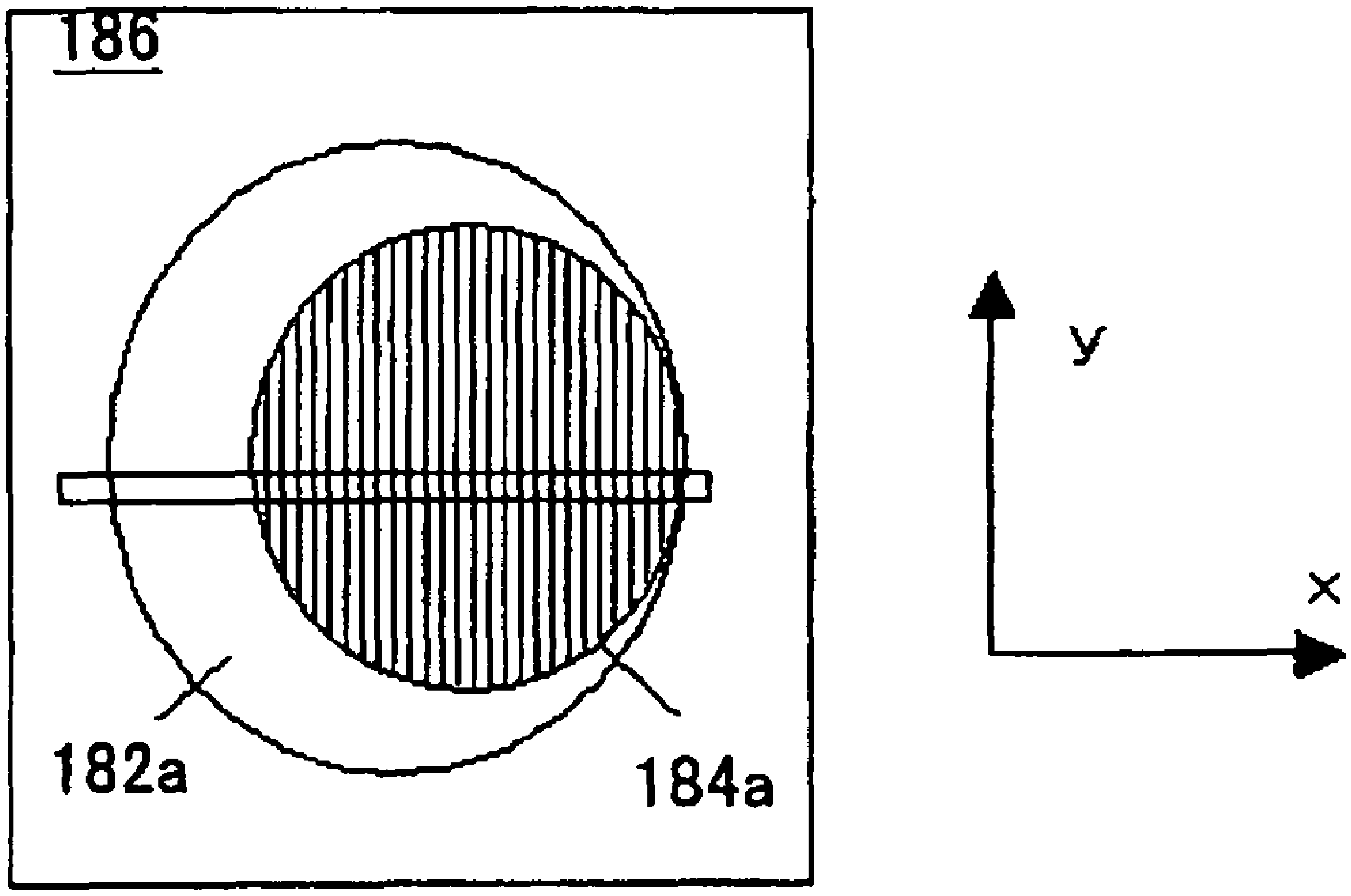


FIG. 12

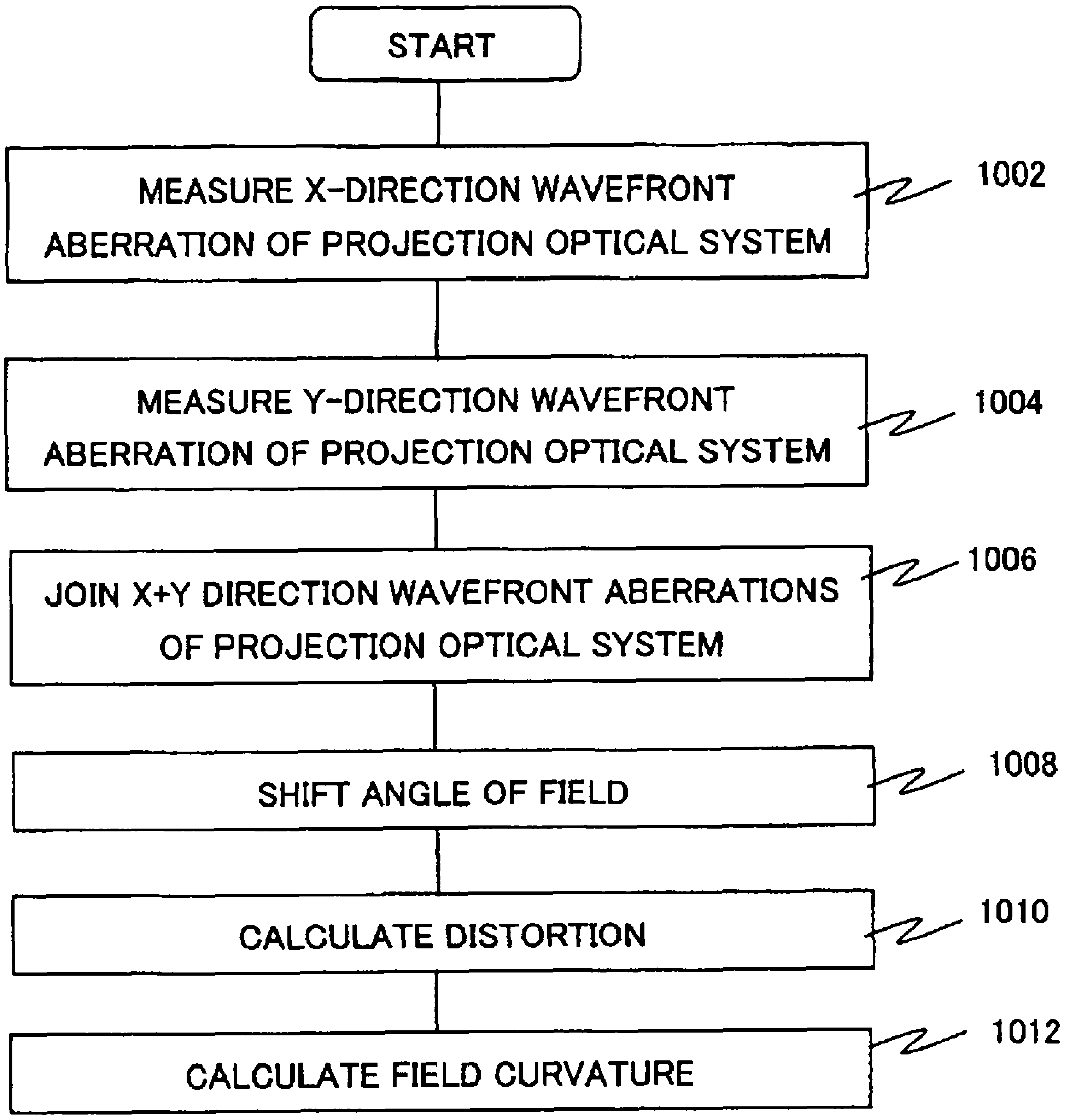

START
MEASURE X-DIRECTION WAVEFRONT ABERRATION OF PROJECTION OPTICAL SYSTEM
1002
MEASURE Y-DIRECTION WAVEFRONT ABERRATION OF PROJECTION OPTICAL SYSTEM
1004
JOIN X+Y DIRECTION WAVEFRONT ABERRATIONS OF PROJECTION OPTICAL SYSTEM
1006
SHIFT ANGLE OF FIELD
1008
CALCULATE DISTORTION
1010
CALCULATE FIELD CURVATURE
1012

FIG. 13

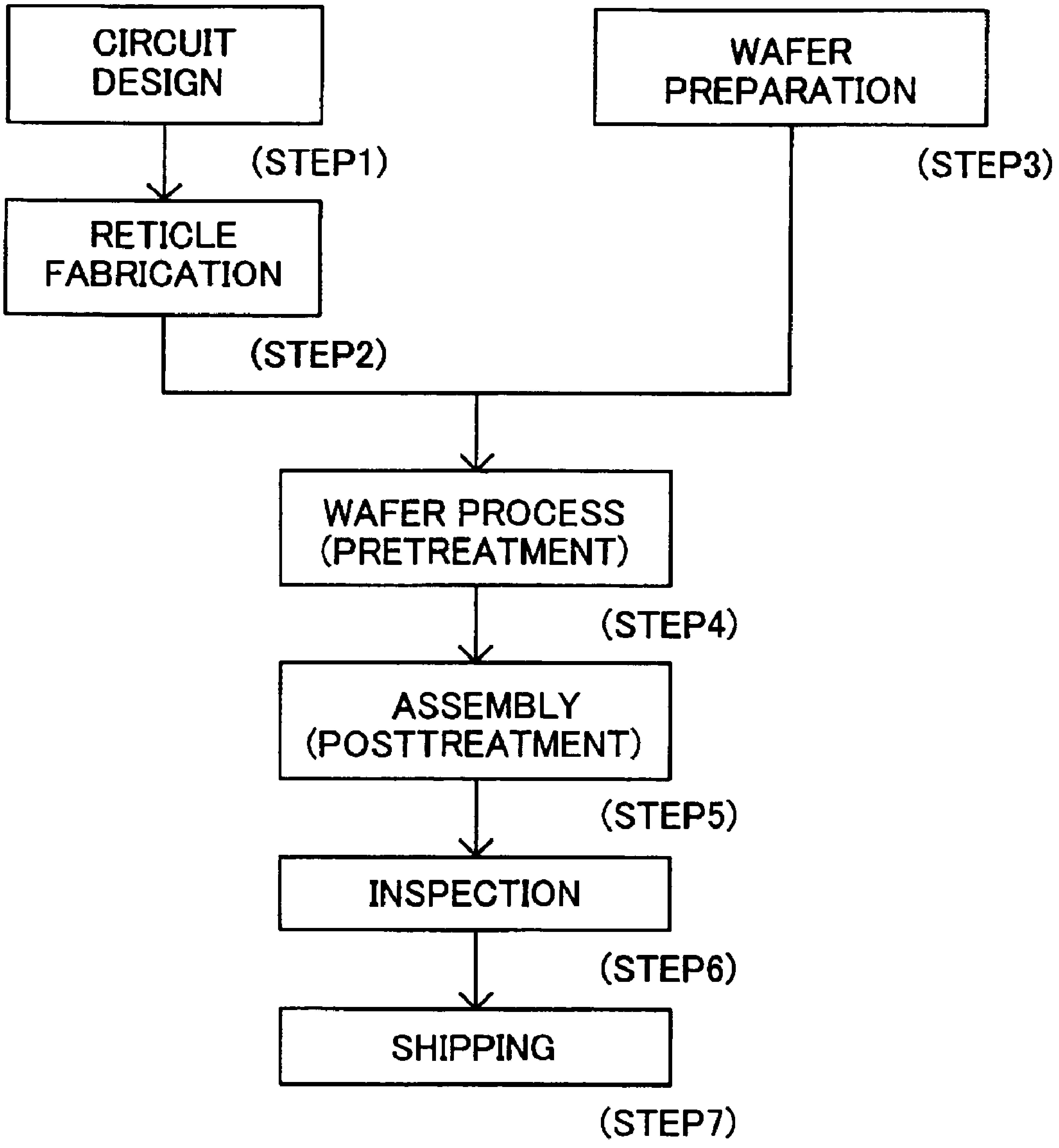

CIRCUIT DESIGN
(STEP1)
RETICLE FABRICATION
(STEP2)
WAFER PREPARATION
(STEP3)
WAFER PROCESS (PRETREATMENT)
(STEP4)
ASSEMBLY (POSTTREATMENT)
(STEP5)
INSPECTION
(STEP6)
SHIPPING
(STEP7)

FIG. 14

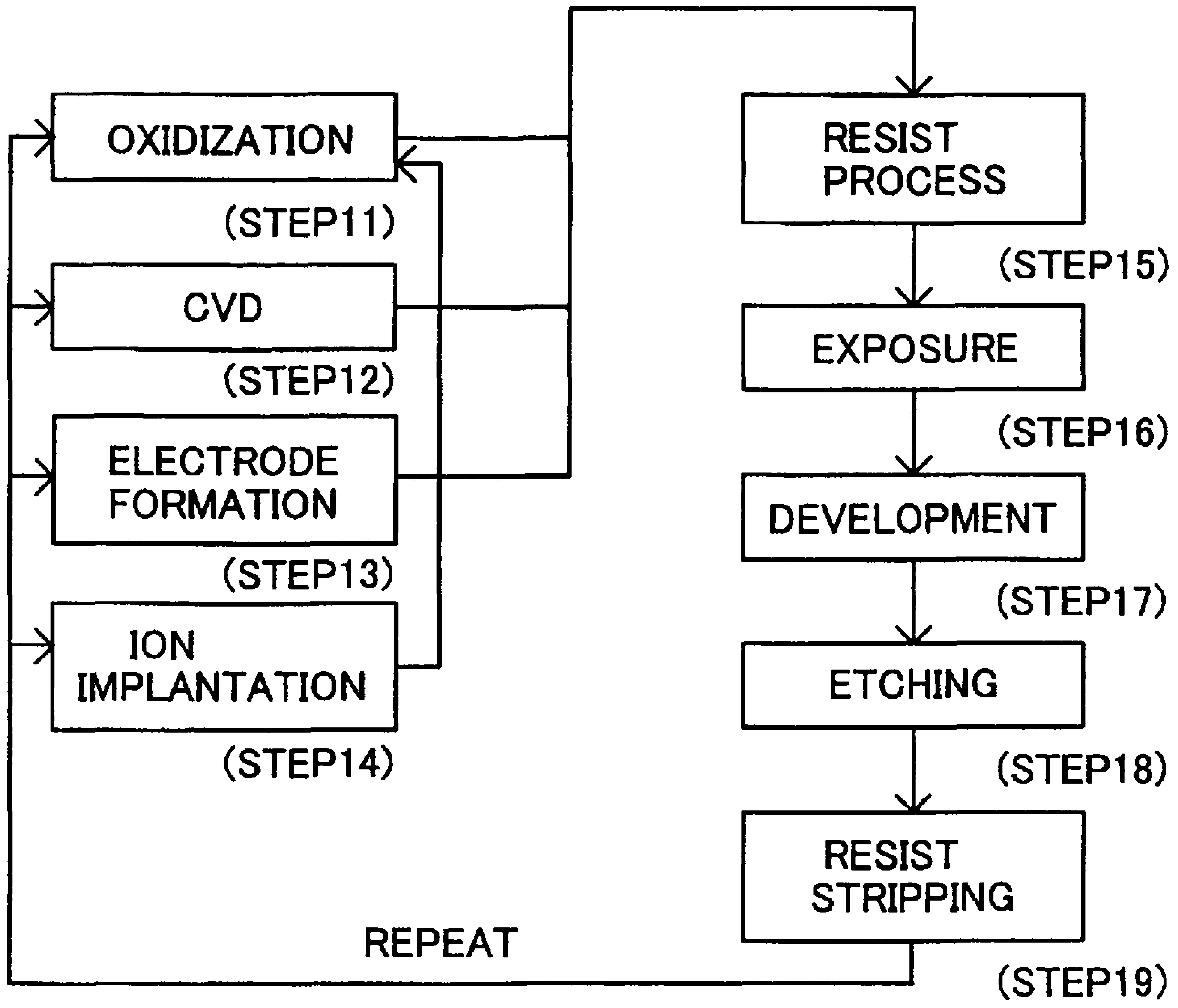

OXIDIZATION
(STEP11)
CVD
(STEP12)
ELECTRODE FORMATION
(STEP13)
ION IMPLANTATION
(STEP14)
RESIST PROCESS
(STEP15)
EXPOSURE
(STEP16)
DEVELOPMENT
(STEP17)
ETCHING
(STEP18)
RESIST STRIPPING
(STEP19)
REPEAT

FIG. 15

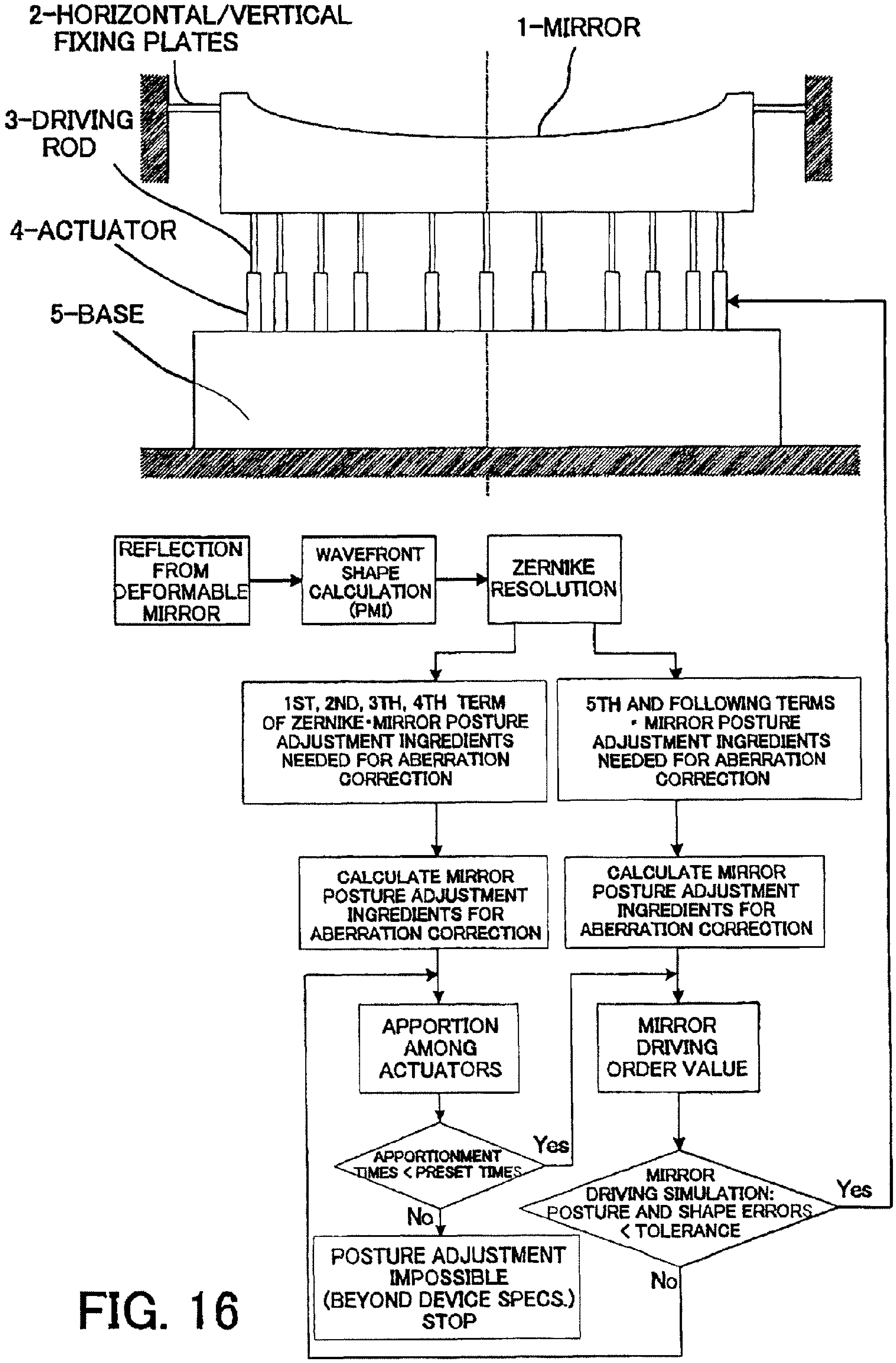

2-HORIZONTAL/VERTICAL FIXING PLATES
1-MIRROR
3-DRIVING ROD
4-ACTUATOR
5-BASE
REFLECTION FROM DEFORMABLE MIRROR
WAVEFRONT SHAPE CALCULATION (PMI)
ZERNIKE RESOLUTION
1ST, 2ND, 3TH, 4TH TERM OF ZERNIKE·MIRROR POSTURE ADJUSTMENT INGREDIENTS NEEDED FOR ABERRATION CORRECTION
5TH AND FOLLOWING TERMS · MIRROR POSTURE ADJUSTMENT INGREDIENTS NEEDED FOR ABERRATION CORRECTION
CALCULATE MIRROR POSTURE ADJUSTMENT INGREDIENTS FOR ABERRATION CORRECTION
CALCULATE MIRROR POSTURE ADJUSTMENT INGREDIENTS FOR ABERRATION CORRECTION
APPORTION AMONG ACTUATORS
MIRROR DRIVING ORDER VALUE
APPORTIONMENT TIMES < PRESET TIMES
Yes
No
MIRROR DRIVING SIMULATION: POSTURE AND SHAPE ERRORS < TOLERANCE
Yes
No
POSTURE ADJUSTMENT IMPOSSIBLE (BEYOND DEVICE SPECS.) STOP

FIG. 16

OPTICAL UNIT AND EXPOSURE APPARATUS HAVING THE SAME

This application claims foreign priority benefit based on Japanese Patent Application No. 2005-116586, filed on Apr. 14, 2005, which is hereby incorporated by reference herein in its entirety as if fully set forth herein.

BACKGROUND OF THE INVENTION

The present invention relates generally to an optical unit and an exposure apparatus having the same, and more particularly, to an optical unit that adjusts the shape of an optical element and an exposure apparatus having the same. This invention is suitable, for example, for an optical unit that adjusts a surface shape of a mirror to correct a wavefront aberration of an optical system including the mirror, as well as an exposure apparatus having such an optical system.

In fabricating a semiconductor device, and the like, by using a photolithography process, a projection exposure apparatus has so far been used that transfers a pattern of a reticle (mask) to a plate. Since such an exposure apparatus is required to precisely transfer a reticle pattern onto a plate, a projection optical system needs to be used that is excellent in imaging performance and well controls aberrations. Due to the recent demand for finer semiconductor devices, a pattern to be transferred has become very susceptible to aberrations of an optical system. For this reason, it is demanded to highly precisely correct wavefront aberration of a projection optical system.

There are two conventional aberration correction approaches—one that adjusts an optical element's surface shape (e.g., see PCT Japanese Publication No. 2003-519404) and the other that changes a position (or posture) of an optical element while maintaining the surface shape of the optical element (e.g., see Japanese Patent Application, Publication No. 2004-064076). PCT Japanese Publication No. 2003-519404 discloses a two-tiered mirror deforming means having actuators connected to the back of a mirror, which correct high-order aberrations, and actuators connected to the actuators via an intermediary deformation plate, which correct low-order aberrations. Japanese Patent Application, Publication No. 2004-064076, discloses a mechanism that uses at least three force actuators to move abreast to an optical axial direction of a mirror or rotate to a direction perpendicular to the optical axis, etc.

PCT Japanese Publication No. 2003-519404 arranges two actuators via an intermediary deformation plate, complicates controls, and results in a large size, due to the two-tier method. Moreover, any asymmetrical aberration causes a moment on the mirror, displacing the mirror's position, but PCT Japanese Publication No. 2003-519404 is silent as to the orientation control. In Japanese Patent Application, Publication No. 2004-064076, actuators act directly on the back surface of the mirror, and the surface shape of a mirror may locally deform during control of the mirror's posture. Any actuator-related part fixed to the back surface of the mirror would deform the mirror due to the weight of the part, but Japanese Patent Application, Publication No. 2004-064076, is silent as to the own-weight compensation.

BRIEF SUMMARY OF THE INVENTION

The present invention is directed to an optical unit that can highly precisely and easily adjust an optical element's posture and surface shape, and an exposure apparatus having the same.

An optical unit according to one aspect of this invention includes a plate having a fixed position, an optical element having a specific optical action, a fixing device for partially fixing the optical element, and a deforming device, located between the plate and the optical element, for applying a deforming force to the optical element to asymmetrically change a surface shape of the optical element.

An optical unit according to another aspect according to this invention includes an optical element having a specific optical action, a deforming device for applying a deforming force to the optical element to change a surface shape of the optical element, and a controller that, when the deforming device applies a deforming force to the optical element, controls the deforming force of the deforming device such that at least part of the optical element is not displaced.

An exposure apparatus including such an optical unit also constitutes an aspect of the present invention. Further, an exposure method as still another aspect of this invention includes the steps of calculating wavefront aberrations of an examined optical system including the optical element, adjusting the examined optical system using the optical unit based on the wavefront aberration of the examined optical system calculated in the calculation step, and exposing a plate using the examined optical system, adjusted in the adjustment step. A device manufacturing method as still another aspect according to the present invention includes the steps of exposing a plate using the exposure apparatus, and developing the exposed plate. A claim for the device manufacturing method that performs the same operation as that of the above exposure apparatus also has an effect on devices as their intermediate and final products. Moreover, such devices include, e.g., semiconductor chips such as LSIs and VLSIs, CCDs, LCDs, magnetic sensors, thin-film magnetic heads, etc.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic sectional view of an optical unit according to a first embodiment of this invention.

FIG. **2** is a schematic sectional view of an optical unit according to a second embodiment of this invention.

FIGS. **3**A-**3**C are views for explaining an effect of the optical unit shown in FIG. **2**.

FIGS. **4**A-**4**B are schematic sectional views of an optical unit according to a third embodiment of this invention.

FIGS. **5**A-**5**C are views for explaining an effect of the optical unit shown in FIGS. **4**A-**4**B.

FIG. **6** is a schematic block diagram of an exposure apparatus as an embodiment of this invention.

FIG. **7** is a view of an optical path including a second illumination optical system, a beam splitting means, and a first mask of a measuring device applicable to the exposure apparatus shown in FIG. **6**.

FIG. **8** is a schematic plan view of the first mask shown in FIG. **7**.

FIG. **9** is a schematic plan view of the beam splitting means shown in FIG. **7**.

FIG. **10** is a schematic plan view of the second mask shown in FIG. **7**.

FIG. **11** is a typical view of a beam exiting from the center of a slit and a window for the second mask shown in FIG. **10**.

FIG. **12** is a schematic plan view showing an example of an interference fringe of a beam exiting from the slit and window shown in FIG. **10**, which the image-pickup means shown in FIG. **7** detects.

FIG. **13** is a flowchart for explaining an operation of the measuring device shown in FIG. **1**.

FIG. **14** is a flowchart for explaining a fabrication of devices (such as semiconductor chips, like ICs, LSIs, and the like, LCDs, CCDs, etc.).

FIG. **15** is a detailed flowchart for a wafer process in Step **4** shown in FIG. **14**.

FIG. **16** is a schematic sectional view of an optical unit of a fourth embodiment of this invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

By referring to the accompanying drawings, a description will be given below of an optical unit **10** according to a first embodiment of the present invention, and an exposure apparatus **100** having the same (see FIG. **6**). Here, FIG. **1** is a schematic sectional view of the optical unit **10**. The optical unit **10** has a mirror **12**, a base **14**, a fixing means, a deforming means **20**, and a controller **30**, as well as a function to adjust the planar shape of the mirror **12**, and its posture. As described below, the optical unit **10** is part of an optical system that makes up the exposure apparatus **100**.

The mirror **12** is an example of an optical element, regardless of whether it is a spherical or an aspheric mirror. It has a reflective surface **12***a* performing a reflex action and a reverse surface **12***b* as a backside, opposed to the reflective surface **12***a*. The reflective surface **12***a* is irrespective of a convex surface or a concave surface. It is preferable that a low-thermal expansion material such as, e.g., ULE, ZeroDure, a superinver, and the like, be used for the mirror **12** to prevent thermal deformation. The base **14** is a basal plate whose position is fixed within the exposure apparatus **100**.

The fixing means is embodied as a support pole **16** in this embodiment, thus fixing the mirror **12** to the base **14** such that, partially, it is not displaced. Since the base **14** is not displaced, a region **12***c* contacting the support pole **16** of the mirror **12** also becomes unable to be displaced. For the support pole **16**, it is desirable to use a highly rigid material with as low-thermal an expansion property as possible. The support pole **16** is provided in the center of the reverse surface **12***b* of the mirror **12**. In this embodiment, the centerline of the support pole **16**, the center of the reverse surface **12***b* (center of gravity), and the center of the base **14** are exemplarily aligned, as shown by a dotted line in FIG. **1**. Since the center of gravity of the mirror **12** is on the centerline of the support pole **16**, no moment acts on the mirror **12**. The present invention sets no limit on the position, shape, size, and number of the fixing means.

The deforming means **20** is composed of multiple pairs of driving rods **22** and actuators **24**. The driving rod **22** has one end that is fixable or contactable to the reverse surface **12***b* of the mirror **12**, being driven by the actuator **24**, such that it is projected or restored. If the driving rod **22** is fixed to the reverse surface **12***b* of the mirror **12**, the mirror **12** receives a compressive and tensile force from the driving rod **22**. If the driving rod **22** merely contacts the reverse surface **12***b*, the mirror **12** receives only the compressive force from the driving rod **22**. The driving rod **22** should preferably be a highly rigid material with as low-thermal an expansion property as possible. The actuator **24** applies a deforming force to the mirror **12** through the driving rod **22**. The actuator **24** includes a linear motor, an electromagnet, another force actuator, a piezoelectric element, and another displacement generation actuator.

The controller **30** is connected to the measuring device **101**, calculating a deforming force applied by the actuator **24** and the driving amount of the actuator **29**. The memory **32** stores information about the current shape of the mirror **12**, a relationship between the deformation of the mirror **12** and the deforming force applied by the actuator **24**, etc.

In its behavior, the controller **30** acquires information about wavefront aberrations from the measuring device **101**, and necessary information, such as a current shape of the mirror **12** from the memory **32**, and then, calculates a mirror shape necessary to correct the wavefront aberration, a distribution of a deforming force to be applied by the actuator **24** necessary for forming such a mirror shape, and the driving amount of the actuator **24** needed to form the distribution of such a deforming force. When correcting aberrations, the controller **30** considers, with respect to the actuator **24**, a driving force resolving power or a driving displacement resolving power, stability, wavefront aberration measurement precision, a mirror system's rigid matrix precision used to calculate the driving force, etc.

In general, since the distribution of a deforming force for correcting an aberration is asymmetrical, the resultant driving force will never become zero. At this time, the support pole **16** fixes the contact region **12***c* so that the latter may not be displaced, and thus, the mirror **12** does not move abreast in a Z direction in FIG. **1** or rotate around the axis vertical to the Z direction. For example, although a resultant moment is generated in which the resultant driving force never becomes zero, such a moment is borne by the support pole **16**, due to which the mirror **12** does not rotate. As a result, the posture of the mirror **12** can be kept within the required bounds of precision, thus eliminating the need to control the posture of the minor **12**. Further, it is needless to say that the optical unit **10** can meet the requirements of the aberration correction having a symmetrical distribution of the deforming force.

According to the present embodiment, since the actuators need not be arranged in a many-tiered way, the structure and control are simple, thus allowing a small apparatus to be maintained. Moreover, no dedicated posture controlling is done, thus eliminating a need for position measurement.

FIG. **2** shows an optical unit **10**A according to a second embodiment of this invention. The optical unit **10**A is different from the optical unit **10** in that it has a cooling mechanism **40** and an own-weight compensation mechanism **50**.

The cooling mechanism **40** cools the actuators **24**. Namely, there are those among the actuators **24** that form a temperature distribution in the optical unit **10**A due to heat generation. Temperature-adjusting the optical unit **10**A as needed enables the mirror **12** to be protected from being thermally deformed, and a thermal effect on exterior materials of the optical unit **10**A to be controlled. For example, when the force actuators **24** use a linear motor or an electromagnet, if a force is continuously applied for a set period of time after the mirror **12** is deformed to a desirable shape in order to maintain the shape, heat generation takes place.

The cooling mechanism **40** of this embodiment includes a bellows **42** and a flow path **44**. The bellows **42** is provided between the mirror **12** and a base **14**A, and forms a space S between the mirror **12** and the base **14**A. Even if the driving section **22** moves, the bellows **42** keeps air-tightness of the space S. The flow path **44** is formed in the base **14**A, and is in a communicative connection with the closed space S. A coolant C circulates in the flow path **44**. The coolant C is supplied from a supply section (not shown) via piping and a flow rate adjustment meter, and is exhausted to a collecting section (not shown). The circulation of the coolant C through the space S makes the actuators **24** cool off. The coolant C is temperature-adjusted air, and the like.

In another embodiment, a cooling jacket is located in which a coolant circulates in each of the actuators **24**. This can effectively cool off the actuators **24**, especially those that heat up. Further, cooling each actuator **24** and circulating a cooling gas to the space S may be simultaneously performed.

The own-weight compensation mechanism **50** has the function of protecting the deformation of the mirror **12** due to its own weight or by forces (hereinafter, simply called "deformation by the own-weight"), other than the deforming force from the actuators **24**. In other words, the mirror **12** is deformed by its own weight, and further, it is also deformed by installing the driving rods **22**. Thus, this embodiment provides the own-weight compensation mechanism **50**, canceling deformation due to the own-weight of the mirror **12**. The own-weight compensation mechanism **50** of this embodiment is embodied by magnets located such that the same polarity is opposed. Each magnet is fixed at the mirror's reverse surface **12***b* and at each actuator **24**. The magnetic force of a magnet may be made up such that it is adjustable. In this way, by eliminating the effect of the mirror own-weight deformation, the actuators **24** are made to generate only the force for deforming the mirror shape, thus relatively controlling heat generation.

When a surface of the mirror is processed, such own-weight deformation should be considered, and the processing may be done so as to compensate for the own-weight deformation, and to obtain a desirable initial mirror shape after the own-weight deformation.

In the optical unit **10**A, the support rods **22** are fixed at the reverse surface of the mirror **12**, and as shown by circles in FIG. **3**A, a total of twenty-four points are arranged, with three points in a radial direction and eight points in a circumferential direction at forty-five degree intervals. A two-dot dashed curve ED in FIG. **3**A is an effective diameter of the mirror **12**. When a target shape of the reflective surface **12***a* inside the effective diameter ED shown in FIG. **3**B is set up in the arrangement shown in FIG. **3**A, a simulation result obtained by driving the driving rods **22** to deform the reflective surface **12***a* is shown in FIG. **3**C. As shown in FIG. **3**C, the reflective surface **12***a* has a surface shape close to the target shape shown in FIG. **3**B. Incidentally, the arrangement shown in FIG. **3**A is just an example, and an arrangement of the driving rods **22** is decided according to a target surface shape of a mirror needed.

Now, by referring to FIG. **4**A and FIG. **4**B, a description will be given of an optical unit **10**B according to a third embodiment of this invention. Here, FIG. **4**A is a top surface view of the optical unit **10**B, and FIG. **4**B is an A-A sectional view of FIG. **4**A. The optical unit **10**B is different from the optical unit **10** in the fixing means. The fixing means of the optical unit **10**B has fixing plates **16**A, in place of the support pole **16**, that are fixed to the side surface **12***d* of the mirror **12**, at least at three or more points. The optical unit **10**B has the advantage that the eigenfrequency of the mirror **12** can be made higher than that of the optical unit **10**. Dark dots in FIG. **4**A denote driving points showing driving positions. In the optical unit **10**B, the driving rods **22** are fixed to the reverse surface **12***b* of the mirror **12**, and a total of thirty-two points are arranged, as shown in FIG. **5**A. A two-dot dashed curve ED in FIG. **5**A is the effective diameter of the mirror **12**. When a target shape of the reflective surface **12***a* inside the effective diameter ED shown in FIG. **5**B is set up in the arrangement shown in FIG. **5**A, a simulation result obtained by driving the driving rod **22** to deform the reflective surface **12***a* is shown in FIG. **5**C. As shown in FIG. **5**C, the reflective surface **12***a* has a surface shape close to the target shape shown in FIG. **5**B. Incidentally, the arrangement shown in FIG. **5**A is just an example, and an arrangement of the driving rods **22** is decided according to a target surface shape of a mirror needed.

It goes without saying that the cooling mechanism **40** and the own-weight compensation mechanism **50** can be applied to the optical unit **10**B.

As described above, if the optical unit **10** or **10**B is used, an aberration can be corrected by applying an asymmetrical deforming force to the mirror **12**, and further, by properly selecting an arrangement of the mirror driving points, it becomes possible to correct low-order to high-order aberrations. In addition, this realizes a small apparatus with a simple structure.

FIG. **16** shows a fourth embodiment of this invention. The mirror **1** is fixed using at least three fixing plates **2** that abridge horizontal and vertical freedom. One end of a driving rod **3** to change the shape of the mirror **1** is connected to the backside of the mirror **1**, and the other end of the driving rod **3** is connected to the actuator **4**. The actuators **4** are located on the base **5**.

The algorithm for deforming the mirror **1** is as follows. Reflective light from the mirror **1** is measured by a wavefront shape measurement instrument (PMI), and the resultant wavefront shape is Zernike-resolved. Each of first, second, third, and fourth terms of the Zernike formula is an amount about the mirror's vertical shift and an amount about its horizontal tilt, showing a change of the mirror's posture, and these are amounts required to adjust the mirror's posture. A fifth and following terms of the Zernike formula are shape ingredients of the mirror necessary for correcting aberrations on the optical system. A driving force needed for adjusting the mirror's posture is calculated, the driving force is apportioned among the actuators **4** that deform the shape of the mirror, and a mirror deformation driving order value is calculated for the actuators **4** together with the driving force needed for the mirror shape deformation. Based on this driving order value, a mirror deformation simulation is implemented to determine whether the posture of the mirror **1** and shape errors are within tolerable values, and if it is found to be below the tolerance, the driving order value is sent to the actuators **4** to deform the shape of the mirror **1** to a shape necessary for aberration correction.

A judgement is made to see if the posture of the mirror **1** and shape errors are within tolerable values, and if they are found to be beyond the tolerance, a mirror shape deformation simulation is performed by changing the rate with which to apportion among the actuators the driving force needed for adjustment of the posture of the mirror. This is iterated, and when the number of iterations is over a preset number, an amount of the posture adjustment will result in being beyond the specifications of the unit, thus being unable to be adjusted.

As a method to apportion a mirror posture adjustment driving force among the actuators, an objective function can be set such that after driving the mirror's deformation, the amount of posture changes and the mirror's shape errors become minimum, thus performing optimization. Further, optimization may be performed using a genetic algorithm.

By use of the above-mentioned method, a shape of the mirror can be controlled such that at least part of an optical element may not be displaced or is displaced within the bounds of tolerance, thus maintaining the mirror's posture, and recovering the mirror's post-deformation shape errors within its tolerance.

Now, referencing FIGS. **6** to **13**, a description will be given of the exposure apparatus **100**. Here, FIG. **6** is a schematic block diagram of the exposure apparatus **100**. The exposure apparatus **100** is a projection exposure apparatus that uses, e.g., a step-and-scan method or a step-and-repeat method to expose a circuit pattern formed on a mask **152** onto an exposed object (plate) **172**. Such an exposure apparatus is suitably applicable to a photolithography process of a submicron or a quarter-micron or less, and a description will be given below of a step-and-scan exposure apparatus (which is also referred to as a "scanner") as an example.

The exposure apparatus **100** has a measuring device **101**, and includes an illumination apparatus, an alignment optical system **120**, a mask **152**, a projection optical system **160**, and a plate **172**.

The illumination apparatus illuminates the mask **152**, having a light source section **105** and illumination optical systems (**110** and **112**). The light source section **105** can use as a light source, e.g., an ArF excimer laser with a wavelength of approximately 193 nm, a KrF excimer laser with a wavelength of approximately 248 nm, and the like. However, the kind of laser is not limited to an excimer laser, and an F_2 laser with a wavelength of about 157 nm and extreme ultraviolet (EUV) light with a wavelength of 20 nm or less (e.g., about 13.5 nm) can also be used.

The illumination optical system is an optical system that illuminates the mask **152**, including a lens, a mirror, an optical integrator, a stop, etc. The illumination optical system of this preferred embodiment has a deflecting optical system **110** and a first illumination optical system **112**. The deflecting optical system **110** deflects a beam of light from the light source section **105**, and guides it to first and second illumination optical systems **112** and **120**. The first illumination optical system **112** is an optical system that illuminates the mask **152**, arranging such optical elements as, e.g., a condenser lens, a fly-eye lens, an aperture stop, a condenser lens, a slit, and an imaging optical system, in this order. In an optical system that utilizes EUV, all the illumination optical systems are composed only of mirrors.

The alignment optical system **120** doubles as the function of illuminating masks (first and second masks **142** and **180** to be described later) that are used by the measuring device **101**, and so, it may also be called as a second illumination optical system in this specification. The alignment optical system **120** makes up an alignment scope as well as making up part of the measuring device **101** as described later. During ordinary exposure, the second illumination optical system **120** is located outside the light path, and FIG. **1** does not include the driving mechanism that drives the alignment illumination optical system **120**. The alignment scope illuminates an alignment mark (not shown) on the mask **152** and compares its reflected light and the reference mark. Further, the alignment mark on a wafer stage **170** is image-formed via the projection optical system **160**, thus aligning the wafer stage **170**.

The mask (or reticle) **152** has a circuit pattern (or an image) formed so as to be transferred, and is supported and driven by the mask stage (or reticle stage) **150**. Diffracted light emitted from the mask **152** goes through the projection optical system **160** to be projected onto the plate **172**. The mask **152** and the plate **172** are optically in a conjugate relationship. Since the exposure apparatus **100** of this embodiment is a scanner, the mask **152** and the plate **172** are scanned at the speed ratio of the reduction ratio to transfer the pattern on the mask **152** onto the plate **172**. On the other hand, if a step-and-repeat type exposure apparatus (also called a "stepper") is used, the exposure operation is carried out with the mask **152** and the plate **172** in a standing-still state. When EUV light is utilized, a reflection type reticle will be used.

The projection optical system **160** may use an optical system solely composed of a plurality of lens elements, an optical system comprised of a plurality of lens elements and at least one concave mirror (a catadioptric optical system), a full mirror type catoptric system, and so on. Any necessary correction of the chromatic aberration may use a plurality of lens units made from glass materials having different dispersion values (Abbe values), or arrange a diffractive optical element, such that it disperses in a direction opposite to that of the lens unit. The measuring device **101** evaluates the optical performance (e.g., wavefront aberrations) of this projection optical system **160**. The projection optical system **160** of this embodiment is a catadioptric or a catoptric optical system, and includes a mirror. For such a mirror, the mirror of the optical devices **10** to **10**C can be applied. When EUV is utilized, the inside of the exposure apparatus **100** is evacuated, but for the gas of the cooling mechanism **40**, gas piping is set up so as not to damage the vacuum atmosphere.

The plate **172** is a processed object, such as a wafer, a liquid crystal plate, and the like, and a photo-resist is applied to it. The plate **172** is installed onto the stage **170** via a chuck (not shown). The stage **170** supports the plate **172** and part of the measuring device **101**. The stage **170** may use any structure known in the art, and thus, a detailed description of its structure and operations is omitted here. For example, the stage **170** uses a linear motor to move the plate **172** and part of the measuring device **101** in X-Y directions. The mask **152** and plate **172** are, for example, scanned synchronously, and the positions of the stage **170** and mask stage **150** are monitored by using the second illumination optical system **120** so that both are driven at a constant speed ratio.

The measuring device **101** shown in FIG. **1** has the alignment optical system (the second illumination optical system) **120**, the first mask **142**, the beam splitting means **146**, the second mask **180**, the image pick-up means **186**, a communication cable **188**, a controller **190**, and a memory **192**. In this embodiment, the measuring device **101** includes an interferometer that evaluates the optical performance of the projection optical system **160** as an examined optical system by detecting its interference fringe. As an interferometer, a line diffraction interferometer (LDI) is used here. However, other interferometers, such as a point diffraction interferometer (PDI) or a lateral shearing interferometer (LSI) may be used instead for the measuring device **101**.

As shown in FIG. **7**, the second illumination optical system **120** has illuminating optical systems **121** and **123**, an illumination optical system field stop **122**, a deflection mirror **124**, and a half mirror **125**. Further, the second illumination optical system **120** also has a condenser lens **126**, optical systems **127** and **129** for imaging systems, a reference mark **128**, and an imaging means **130**. Here, FIG. **7** is a light path diagram that includes the second illumination optical system **120** of the measuring device **101**, first mask **142** and beam splitting means **146**.

The optical system **121** is a condenser optical system that condenses light to the field stop **122**, and the optical system **123** is a collimator that converts the beam exiting from the field stop **122** into parallel light. The deflection mirror **124** and the half mirror **125** deflect the beam from the optical system **124**, and the condenser lens **126** condenses light to the first mask **142**. Light supplied from the light source section **105** via the deflecting optical system **110** goes through the optical elements **121** to **126**, being projected to the projection optical system **160**. The optical elements **125** through **130** function as an alignment scope for the mask stage **150** and the wafer stage **170**, and so, the condenser lens **126** functions as an objective lens for alignment of the mask pattern and plate **172**.

The first mask **142** is installed on the second illumination optical system **120** via the plate **140**, having a pair of slits **144***a* and **144***b*, as shown in FIG. **8**. Here, FIG. **8** is a schematic block diagram of the first mask **142**. The first mask **142** is composed of two kinds of slits **144***a* and **144***b* arranged at ninety degrees. The slits **144***a* and **144***b* are the same in width and length, but different only in direction.

As described later, the condenser lens **126** can illuminate only the slits **144***a* or **144***b*. For this objective, the first mask **142** may be installed in a movable way with respect to the illumination optical system **120** via a driving mechanism (not shown), or the driving mechanism may be provided on the side of the illumination optical system **120**.

In this embodiment, the direction in which the slit **144***a* extends may be called a y-direction, and the direction in which the slit **144***b* extends may be called an x-direction. Further, in this embodiment, the slit **144***a* may be called a zero-degree direction slit, and the slit **144***b* a ninety-degree direction slit. The width Δr of the slits **144***a* and **144***b* is a width equal to or less than a diffraction limit determined by the following formula, assuming that the numerical aperture at the reticle side of the projection optical system **160**, i.e., the object side is ANo, and the exposure wavelength is λ,

$$\Delta r < 0.5 \cdot \lambda / ANo \quad (1)$$

By determining the width of the slit, as shown by the mathematical expression (1), diffracted light from the slit can be regarded to be an equiphase. The length Lr is longer the better from the standpoint of the light amount, but it should be made smaller than the so-called "isoplanatic region" that an aberration of the projection optical system **7** can be regarded as the same.

The beam splitting means **146** amplitude-splits a beam diffracted from the slits **144***a* and **144***b*. The beam splitting means **146** is structured as a grating, e.g., having the structure shown in FIG. **9**. The beam splitting means **146** is set up on a transparent plate (not shown) located on the mask stage **150**. Alternatively, a plate (not shown), on which a diffraction grating is arranged, may be prepared such that it is mounted on the mask stage **150** instead of the mask **152**.

In FIG. **9**, the beam splitting means **146** is an amplitude type diffraction grating. When the slit **144***a*, which is long in the y-direction, is used for measurement, a diffraction grating is used in which lines are arranged in the x-direction, as with the diffraction grating **148***a* in FIG. **9**. Due to the diffraction grating **148***a*, a beam is split in the x-direction in the figure. Multiple split beams are image-formed onto the second mask **180** via the projection optical system **160**. The diffraction gratings **148***a* and **148***b* are driven by the driving mechanism of the mask stage **150** where the beam splitting means **146** is installed.

As shown in FIG. **10**, the second mask **180** includes a pair of the slit **181***a* and the window **183***a* located in a zero-degree direction (y-direction), and a pair of the slit **181***b* and the window **183***b* located in the ninety-degree direction (x-direction). The pair of the slit **181***a* and the window **183***a*, and the pair of the slit **181***b* and the window **183***b* have the same width and interval, but different directions. The width Δw of the slits **181***a* and **181***b* is a width that is equal to or less than the diffraction limit determined by the following formula, assuming that the numerical aperture at the wafer side of the projection optical system **160**, i.e., the image side is NAi:

$$\Delta w < 0.5 \cdot \lambda / NAi. \quad (2)$$

By determining the width of the slits **181***a* and **181***b* as with the mathematical expression 2, light diffracted from the slits **181***a* and **181***b* can be regarded to be an equiphase within the range of Nai.

The width Δw' of the windows **183***a* and **183***b* is determined by a spatial frequency of the projection optical system to be measured. When desiring to measure as far as a radio-frequency wave, make the width wide, and when only a low-frequency wave is measured, make it narrow. If the spatial frequency of the pupil of the projection optical system **160** is f, Δw can be given by the following equation. Here, it is assumed that the frequency f of the wavefront aberration is one where the pupil's radius forms one cycle.

$$\Delta w' = 2 \times f \times \lambda / NAi \quad (3)$$

The length Lw is the longer, the better from the standpoint of the light amount, but it should be made smaller than the so-called isoplanatic region that is regarded to be the same by the aberration of the projection optical system **160**.

The image pick-up means **186** is composed of a CCD, and the like, detecting an interference fringe of two beams from the slit **181***a* or **181***b* and the window **183***a* or **183***b*. The cable **188** connects the image pick-up means **186** and the controller **190** so that they can communicate. The controller **190** obtains phase information from the output of the image pick-up means **186**. Further, it controls each part of the exposure apparatus **100**. The memory **192** stores the measurement method shown in FIG. **8** as explained later, the processing method for the controller **190** to obtain phase information from the output of the image pick-up means **186**, phase information that the controller obtains, the controlling method for the controller **190** to perform, and other data. The controller **190** may double as the controller **30**, and the memory **192** may double as the memory **32**.

Referring to FIG. **13**, a description will be given of the operation of the measuring device **101**. Here, FIG. **13** is a flowchart for explaining how the measuring device **101** operates. At first, an x-direction wavefront aberration of the projection optical system **160** is measured (Step **1002**).

In FIG. **6**, a beam exiting from the light source section **105** is deflected by the deflecting optical system **110** to the second illumination optical system **120** for imaging performance measurement. The beam from the deflecting optical system **110** is condensed by the illumination optical system optical system **121**, being irradiated to the field stop **122**. The field stop **122** is made so large as to irradiate the first mask **142** arranged onto the plate **140**. The beam from the field stop **122** is turned into parallel light by the optical system **123**, is deflected by the deflection mirror **124** and the half mirror **125**, and is made incident on the condenser lens **126**. The condenser lens **126** condenses light into the first mask **142**.

In Step **1002**, a driving mechanism (not shown) relatively moves the illumination optical system **120** and the mask **142** to ensure that the beam from the condenser lens **126** is irradiated only to the zero-degree direction slit **144***a*.

Since the slit **144***a* has a width equal to or less than the diffraction limit, light exiting from the slit **144***a* becomes diffracted light having an equiphase wavefront with respect to the x-direction in the figure. On the other hand, diffraction of light in the y-direction or longitudinal direction of the slit **144***a* is small. Accordingly, at least with respect to the y-direction in FIG. **8**, a beam with a numerical aperture equal to or greater than the numerical aperture on the object side of the projection optical system **160**, i.e., reticle side, is irradiated to the slit **144***a* through the condenser lens **126**. By so doing, the whole surface of the optical pupil of the projection optical system **160** will be irradiated by light. Moreover, light diffracted in a short direction of the slit **144***a* will become an equiphase.

The beam is diffracted at the slit **144***a*, is turned into an x-direction equiphase wavefront, and undergoes an amplitude division in the x-direction through the diffraction grating of the beam splitting means **146**. Multiple beams that underwent the amplitude division are image-formed onto the second mask **180** via the projection optical system **160**. In other words, of those beams diffracted at the slit **144***a* and diffracted at the diffraction grating **148***a*, a zero-order beam is image-formed at the slit **181***a* of the beam splitting means **180**, and a first-order beam is image-formed at the window **183***a*. The pitch of the diffraction grating **148***a* is set in that way, and the position of the beam splitting means **180** is set by the mask stage **150** accordingly. Other diffracted lights are shielded by the shielding parts of the mask **180**. A negative first order beam may be used in lieu of the plus first-order beam.

The beam having passed the window **183***a* is affected by the wavefront aberration of the projection optical system **160**. On the other hand, since the slit **181***a* has a width equal to or less than the diffraction limit, light exiting from the slit **181***a* spreads in the x-direction in the figure, becoming diffracted light having an equiphase wave, which has lost wavefront aberration information of the projection optical system **160**. FIG. **11** shows a typical view of light emitted from the center of the slit **181***a* and the window **183***a*. It can be understood that light going through the slit **181***a* forms an ideal cylindrical wavefront **182***a* or an ideal elliptical wavefront **182***a*, and light having gone through the window **183***a* is an examined wavefront **184***a*.

FIG. **12** shows an example of an interference fringe made by the lights exiting from the center of the slit **181***a* and the window **183***a*, which are detected by the image pick-up means **186**. Two pupil images of the projection optical systems **160** are taken whose centers are off by the interval between the slit **181***a* and the window **183**, and an interference fringe comes into being in the area common to both. The x-direction of the beam **182***a* is an equiphase, and thus, if phase information is taken out of the interference fringe in FIG. **12**, an x-direction wavefront aberration of the projection optical system **160** can be found. For acquisition of the phase information, the so-called fringe scan method is used. In the fringe scan method, while the mask stage **150** is scanning the diffraction grating **148***a* by about one pitch in a direction vertical to the line of the diffraction grating, namely, in an x-direction, the image pick-up means **186** takes several images of an interference fringe.

Several images taken of the interference fringe are sent from the image pick-up means **186** to the controller **190** via the cable **188**, and the controller **190** takes out phase information. When the controller **190** acquires the phase information, e.g., an electronic moiré method may be used. In this embodiment, since an interference fringe has a carrier fringe as shown in FIG. **7**, the imaged interference fringe is multiplied by the carrier fringe that the controller **190** prepares or has prepared beforehand and stored in the memory **192**, thus being processed. If an electronic moiré method is used, phase information can be taken out of one picture of the interference fringe, which is advantageous in terms of time.

Next, a y-direction wavefront aberration of the projection optical system **160** is measured (Step **1004**). Similar to Step **1002**, the condenser lens **126** condenses light to the first mask **142**. At this time, in Step **1004**, the driving mechanism (not shown) moves the illumination optical system **120** and the mask **142** relatively, ensuring that the beam from the condenser lens **126** is irradiated only to the ninety-degree direction slit **144***b*.

Since the slit **144***b* has a width equal to or less than the diffraction limit, light exiting from the slit **144***b* spreads in the y-direction in the figure, and becomes diffracted light having an equiphase wavefront with respect to the y-direction. On the other hand, diffraction of light in the x-direction or longitudinal direction of the slit **144***b* is small. Accordingly, at least with respect to the x-direction in FIGS. **3**A-**3**C, a beam with a numerical aperture equal to or greater than the numerical aperture on the projection optical system **160**'s object side, i.e., reticle side, is irradiated to the slit **144***a* by using the condenser lens **126**. This will permit light to be irradiated across the whole optical pupil surface of the projection optical system **160**. Moreover, light diffracted in a short direction of the slit **144***b* will become equiphase.

The beam is diffracted at the slit **144***a*, is turned into a y-direction equiphase wavefront, and undergoes the amplitude division in the y-direction through the diffraction grating of the beam splitting means **146**. Multiple beams that underwent the amplitude division are image-formed onto the second mask **180** via the projection optical system **160**. In other words, of those beams diffracted at the slit **144***b* and diffracted at the diffraction grating **148***b*, a zero-order beam is image-formed at the slit **181***b* of the beam splitting means **180**, and a plus first-order beam is image-formed at the window **183***b*. The pitch of the diffraction grating **148***b* is set in that way, and the position of the beam splitting means **180** is set by the mask stage **150** accordingly. Other diffracted lights are shielded by the shielding parts of the mask **180**. A negative first-order beam may be used instead of the plus first-order beam.

The beam having passed the window **183***b* is affected by the wavefront aberration of the projection optical system **160**. On the other hand, since the slit **181***b* has a width equal to or less than the diffraction limit, light exiting from the slit **181***b* spreads in the y-direction in the figure, and becomes diffracted light having, with respect to the y-direction, an equiphase wavefront and no more information about wavefront aberrations of the projection optical system **160**. For acquisition of the phase of the interference fringe, the fringe scan method is used similarly to that in Step **1002**. In the fringe scan method, while the mask stage **150** is scanning the diffraction grating **148***b* by about one pitch in a direction vertical to the line of the diffraction grating, namely, in an x-direction, the image pick-up means **186** takes several images of an interference fringe.

Several images taken of the interference fringe are sent from the image pick-up means **186** to the controller **190** via the cable **188**, and the controller **190** acquires phase information. When the controller acquires the phase information, an electronic moiré method, e.g., may be used. Since the wavefront from the slit **181***b* is equiphase in the y-direction, the phase measured in Step **1004** includes information about y-direction wavefront aberration of the projection optical system **160**.

Next, the controller **190** joins information about x and y direction wavefront aberration of the projection optical system **160** acquired in steps **1002** and **1004** to obtain the wave front aberration information of the projection optical system **160** (Step **1006**). Further, by repeating steps **1002** to **1006** while changing an angle of field, it is possible to obtain wavefront aberration information across the whole angles of field of the projection optical system **160** (Step **1008**). The controller **190** extracts rotational asymmetrical ingredients from the wavefront aberration at each angle of field, thereby finding distorted ingredients of the projection optical system **160**, too (Step **1010**). Further, the controller **190** can find field curvature of the projection optical system **160** from the rotational symmetrical ingredients of the wavefront aberration (Step **1012**).

Thus, it is possible to measure the wavefront aberration of the projection optical system **160***a* at multiple field angles, distortions within field angles, and field curvature. Naturally, it is possible to carry out steps **1002** to **1006** as to one field angle, and to measure wavefront aberration only at one field angle.

As described above, this embodiment has the second illumination optical system **120** that doubles as an alignment optical system aligning the mask **152** and the plate **172**. It uses the condenser lens **126** to irradiate a beam onto an alignment mark (not shown) located on the mask stage **150**. The irradiated alignment mark is used by the condenser lens **126** and a relay lens **127** to form an intermediate image on the reference mark **128**. The intermediate image of the alignment mark and the reference mark are image-formed to the imaging means **130** of a CCD, and the like, by an erector lens **129**. The amount of difference between the alignment mark image and reference mark image formed on the imaging means **130** is measured to determine the positioning of the mask stage **150**. In a similar manner, the alignment mark (not shown) on the wafer stage **170** can be image-formed to the imaging means **130** via the projection optical system **160** to align the wafer stage **170**.

In this embodiment, since the alignment scope and a part of the measuring device **101** (illumination section) are made common, the apparatus is simplified, contributing to cost reduction. Naturally, these devices can be made separate.

Next, referring to FIGS. **14** and **15**, a description will be given of an embodiment of a device manufacturing method using the afore-mentioned exposure apparatus **100**. FIG. **14** is a flowchart for explaining a fabrication of devices (e.g., semiconductor chips such as ICs and LSIs, LCDs, CCDs, etc.). In this embodiment, a description will be given of fabrication of a semiconductor chip as an example. Step **1** (circuit design) designs a semiconductor device circuit. Step **2** (mask fabrication) forms a mask having a designed circuit pattern. Step **3** (wafer making) manufactures a wafer using materials such as silicon. Step **4** (wafer process), which is referred to as a pretreatment, forms actual circuitry on the wafer through photolithography using the mask and wafer. Step **5** (assembly), which is also referred to as a post-treatment, forms into a semiconductor chip the wafer formed in Step **4** and includes an assembly step (e.g., dicing, bonding), a packaging step (chip sealing), and the like. Step **6** (inspection) performs various tests for the semiconductor device made in Step **5**, such as a validity test and a durability test. Through these steps, a semiconductor device is finished and shipped (Step **7**).

FIG. **15** is a detailed flowchart of the wafer process in Step **4**. Step **11** (oxidation) oxidizes the wafer's surface. Step **12** (CVD) forms an insulating film on the wafer's surface. Step **13** (electrode formation) forms electrodes on the wafer by vapor disposition and the like. Step **14** (ion implantation) implants ions into the wafer. Step **15** (resist process) applies a photosensitive material onto the wafer. Step **16** (exposure) uses the exposure apparatus **300** to expose a circuit pattern on the mask onto the wafer. Step **17** (development) develops the exposed wafer. Step **18** (etching) etches parts other than a developed resist image. Step **19** (resist stripping) removes unused resist after etching. These steps are repeated, and multilayer circuit patterns are formed on the wafer. The fabrication method of the present embodiment may manufacture higher quality devices than does the prior art. In this manner, the device fabricating method that uses the exposure apparatus **100** and the device as a final product serve as other aspects according to the present invention.

Further, the present invention is not limited to these preferred embodiments, and various variations and modifications may be made without departing from the spirit and scope of the present invention. For example, the optical units **10** to **10**C are not limited to projection optical systems, and can be applied to illumination optical systems.

What is claimed is:

1. An optical unit comprising:

a plate;

an optical element;

a deforming device, located between said plate and said optical element, for applying a deforming force to said optical element, asymmetrically changing a surface shape of said optical element, wherein said deforming device includes (i) a plurality of deforming poles for contacting a back surface of said optical element and (ii) actuators for linearly displacing said plurality of deforming poles between said plate and said optical element; and

a support pole, which does not include an actuator, one end of said support pole being connected to said plate and the other end of said support pole being connected to a central portion of the back surface of said optical element, wherein said support pole rigidly fixes said optical element to said plate and prevents displacement of at least a portion of said optical element, in order to counter moments applied by the deforming force of said deforming device,

wherein each of said plurality of deforming poles of said deforming device are located closer to a circumferential edge of said optical element than is said support pole.

2. An optical unit according to claim **1**, further comprising:

a measuring device for measuring aberration of said optical element; and

a controller for calculating a driving amount of at least one of said plurality of actuators based on a measurement result of said measuring device, and for controlling the deforming force of said deforming device.

3. An optical unit according to claim **1**, further comprising a cooling mechanism that cools said deforming device.

4. An optical unit according to claim **1**, further comprising a shape maintaining mechanism that prevents deformations of said optical element caused by an own weight of said optical element.

5. An optical unit according to claim **4**, wherein said shape maintaining mechanism includes (i) a first plurality of magnets located along the back surface of the optical element and (ii) a second plurality of magnets at each of the plurality of actuators such that the same polarity is opposed along said deforming device.

6. An optical unit according to claim **1**, wherein said plurality of deforming poles of said deforming device contact the back surface of said optical element with three points in a radial direction of said optical element, and eight points in a circumferential direction of said optical element, at forty-five degree intervals.

7. An optical unit according to claim **1**, wherein said support pole is made of a highly rigid material with a low-thermal expansion property.

8. An exposure apparatus comprising:

(a) an optical unit comprising:

(i) a plate;

(ii) an optical element;

(iii) a deforming device, located between said plate and said optical element, for applying a deforming force to said optical element, asymmetrically changing a surface shape of said optical element, wherein said deforming device includes (1) a plurality of deforming poles for contacting a back surface of said optical element and (2) actuators for linearly displacing said plurality of deforming poles between said plate and said optical element;

(iv) a support pole, which does not include an actuator, one end of said support pole being connected to said plate and the other end of said support pole being connected to a central portion of the back surface of said optical element, wherein said support pole rigidly fixes said optical element to said plate and prevents displacement of at least a portion of said optical element, in order to counter moments applied by the deforming force of said deforming device; and

(b) an exposure unit for exposing an original pattern onto said plate,

wherein each of said plurality of deforming poles of said deforming device are located closer to a circumferential edge of said optical element than is said support pole.

9. A device manufacturing method comprising the steps of:

(a) exposing an original pattern onto a plate with an exposure apparatus comprising:

(i) a plate;

(ii) an optical element;

(iii) a deforming device, located between the plate and the optical element, for applying a deforming force to the optical element, asymmetrically changing a surface shape of the optical element, wherein the deforming device includes (1) a plurality of deforming poles for contacting a back surface of the optical element and (2) actuators for linearly displacing the plurality of deforming poles between the plate and the optical element;

(iv) a support pole, which does not include an actuator one end of the support pole being connected to the back surface of the plate and the other end of the support pole being connected to a central portion of the back surface of the optical element, wherein the support pole rigidly fixes the optical element to the plate and prevents displacement of at least a portion of the optical element, in order to counter moments applied by the deforming force of the deforming device; and

(v) an exposure unit for exposing an original pattern onto the plate; and

(b) developing the plate that has been exposed, in order to manufacture a device,

wherein each of the plurality of deforming poles of the deforming device are located closer to a circumferential edge of the optical element than is the support pole.

10. An exposure apparatus comprising:

(a) an optical unit comprising:

(i) a plate;

(ii) an optical element;

(iii) a deforming device, located between said plate and said optical element, for applying a deforming force to said optical element, asymmetrically changing a surface shape of said optical element, wherein said deforming device includes (1) a plurality of deforming poles for contacting a back surface of said optical element and (2) actuators for linearly displacing said plurality of deforming poles between the plate and said optical element; and

(iv) a support pole, which does not include an actuator, one end of said support pole being connected to said plate and the other end of said support pole being connected to a central portion of the back surface of said optical element, wherein said support pole rigidly fixes said optical element to said plate and prevents displacement of at least a portion of said optical element, in order to counter moments applied by the deforming force of said deforming device;

(b) a calculator for calculating wavefront aberrations of said optical element;

(c) an adjustor for adjusting a deforming force of said deforming device based on the calculated wavefront aberrations; and

(d) an exposure unit for exposing an original pattern onto said plate,

wherein each of said plurality of deforming poles of said deforming device are located closer to a circumferential edge of said optical element than is said support pole.

11. An optical unit comprising:

a plate;

an optical element;

a deforming device, located between said plate and said optical element, for applying a deforming force to said optical element, asymmetrically changing a surface shape of said optical element, wherein said deforming device includes (i) a plurality of deforming poles for contacting a back surface of said optical element and (ii) actuators for linearly displacing said plurality of deforming poles between said plate and said optical element; and

a support pole, which does not include an actuator, one end of said support pole being connected to said plate and the other end of said support pole being connected to a central portion of the back surface of said optical element, wherein said support pole rigidly fixes said optical element to said plate,

wherein each of said plurality of deforming poles of said deforming device are located closer to a circumferential edge of said optical element than is said support pole.

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